Gamma imaging

Introduction and Definitions

1) Nuclide: a nucleus with a specific *Z and A*

2) Isotopes: nuclides with the same Z but different N (and so A)

- They Have the same position in periodic table , chemical and metabolic properties
- Have different physical properties
- Examples
  - $^{1}H_{1}$ and $^{2}H_{1}$,
  - $^{15}O_{8}$ and $^{16}O_{8}$

3) Isobars: nuclides with the same A but different Z:

- Examples:
  - $^{14}C_{6}$ and $^{14}N_{7}$

4) isotones: nuclides with the same N but different Z

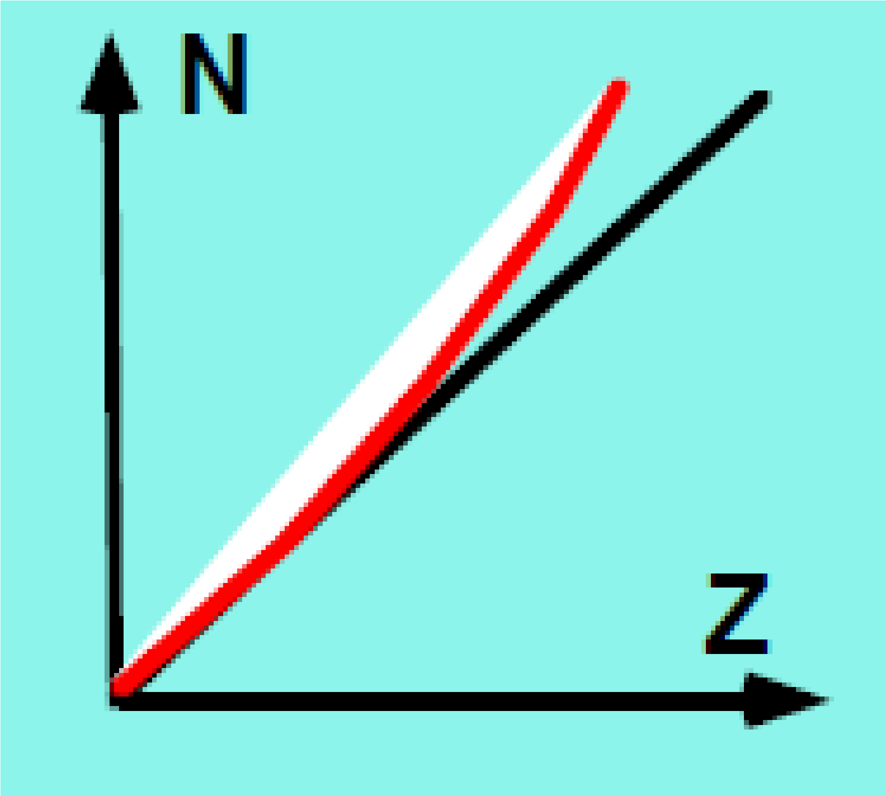
- Examples
  - $^{3}H_{1}$ and $^{4}He_{2}$

5) isomers: nuclides with the same A and Z but different energy levels

$^{99m}_{43}Tc$ **and** $^{99}_{43}Tc$

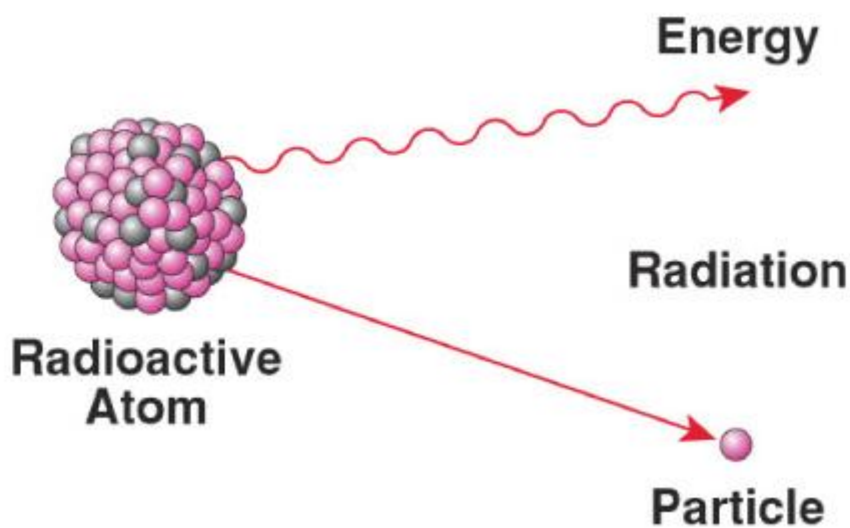
Stability of nucleus

- Nuclear binding energy: energy needed to counteract the electrostatic repulsion between the protons.
- The repulsive forces between protons ↑with ↑Z → stronger nuclear forces provided by more neutrons are needed
  - Stable light nuclei (↓ Z)→ N = Z
  - Stable heavy nuclei (↑Z)→ N > Z
- Most of nuclei existent in the world are stable



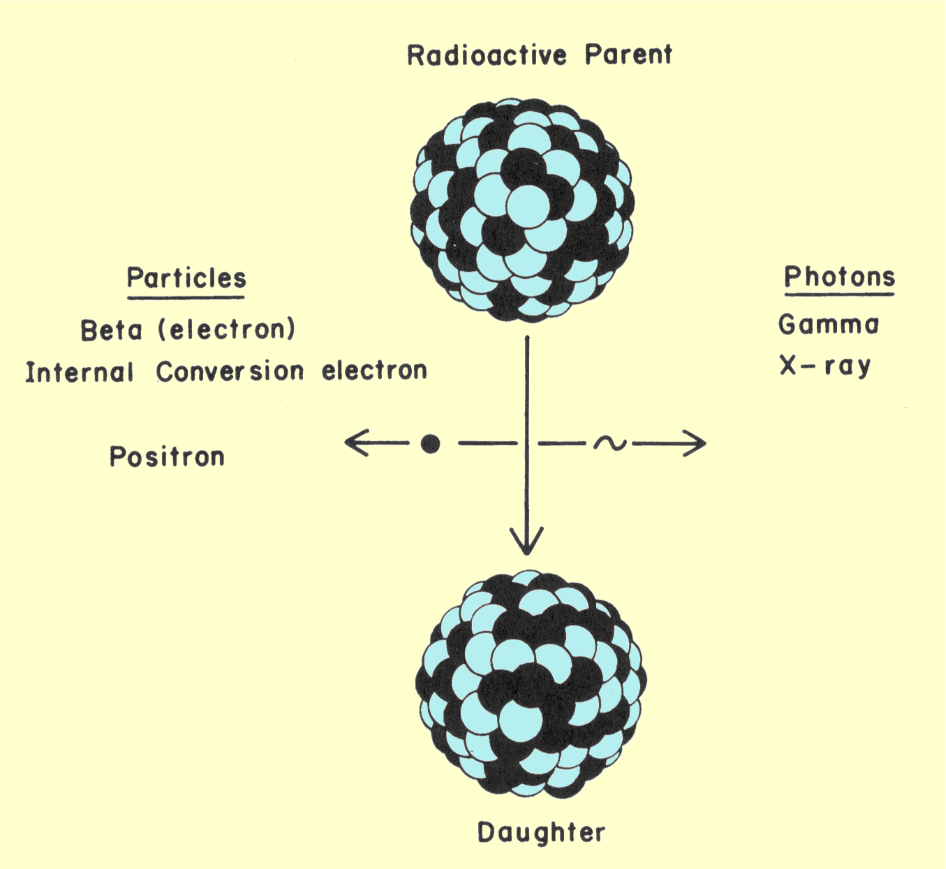
Radionuclide:

- Definition: unstable nuclei having neutron excess or deficit



Radioactive decay:

- Definition: process of spontaneous transformation of radionuclide until it become stable with emission of any of combination of alpha , beta and gamma radiation
- Radioactive decay is a stochastic process (governed by statistical laws of chance)
  – i.e. Fraction of nuclei which will decay is constant, but we can not know which nucleus will decay



Production of radionuclides

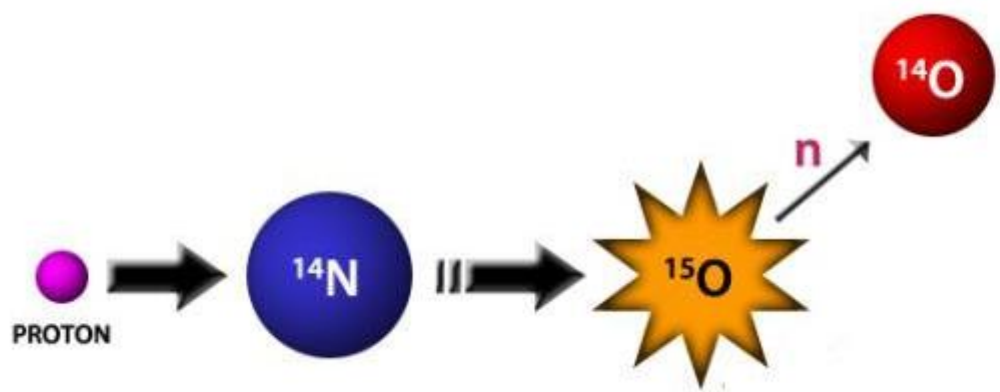
Radionuclide used in imaging must be produced artificially by one of the following methods

<u>1) nuclear reactors:</u>

- Additional neutron is forced into a stable nucleus → unstable nucleus with neutron excess
- Example: $Mo^{98} + n \rightarrow Mo^{99}$
- By this process:
  - Z of the material ……….
  - A of the material ……….
- Radionuclide formed by the reactors can not be separated from original stable nuclei (same chemical properties) i.e. can not be made carrier free

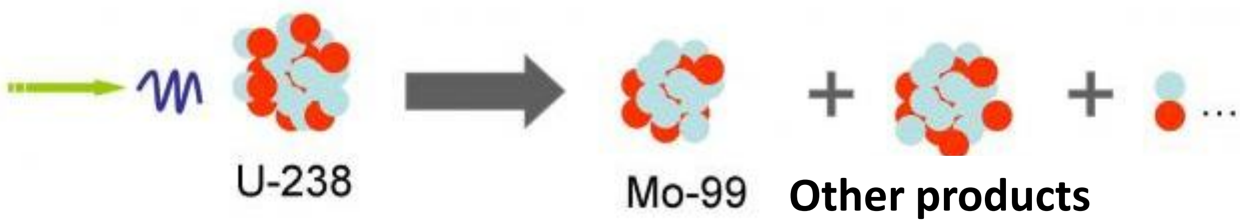
2- cyclotron:

- Addition proton is forced into a stable nucleus knocking out a neutron → unstable nucleus with neutron deficit
- Example: $O^{18} + P \rightarrow F^{18} + n$
- By this process:
  - Z of the material ……….
  - A of the material ……….
- Characteristics:
  - radionuclide formed in the cyclotron can be separated from original stable nuclei (different chemical properties) i.e. can be made carrier free
  - Short lived (low half life) → must be used close to the cyclotron
- N.B: other +ve charged ions can be accelerated in the cyclotron (e.g. alpha particles)



3- fission products:

- the nuclei of atoms are split, causing energy to be released.
- Extracted from spent fuel of nuclear reactor
- Daughters can be made **carrier free**
- **Example:**



4- generators:

- Relatively Long lived radioactive parent → daughter products
- Example: Mo^{99}/Tc^{99m} (see later)

Types of Radioactive transformation (decay)

1) Radionuclide with neutron excess:

Process of β⁻ decay:

- β^- = electron
- neutron changes into proton + electron which is ejected from the nucleus with high energy

•Example:

$^{131}I_{53} \rightarrow \; ^{131}Xe_{54} + \beta^-$

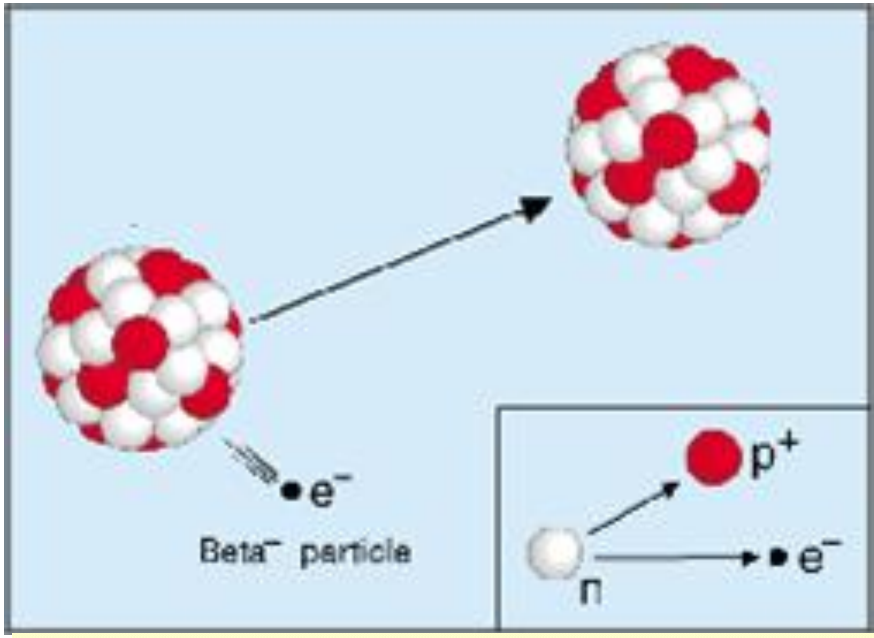
•So that:

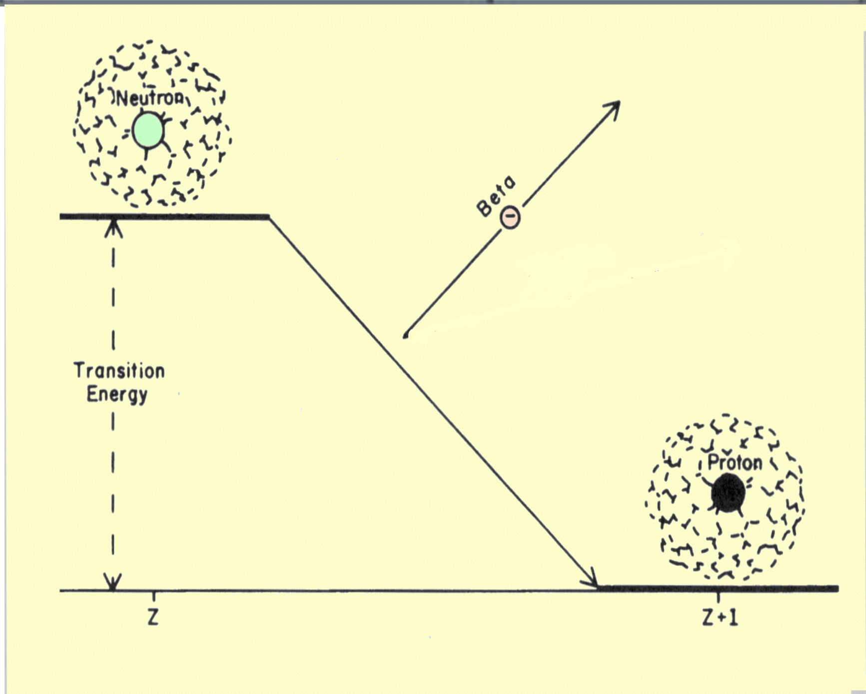
Z is …………………..

A is …………………..

N.B: The product nucleus is nearly always contain excess energy

It loses this energy (usually immediately) in the form of gamma ray (with energy specific to the parent nucleus)





2) Radionuclide with neutron deficit:

A- Process of β⁺ decay:

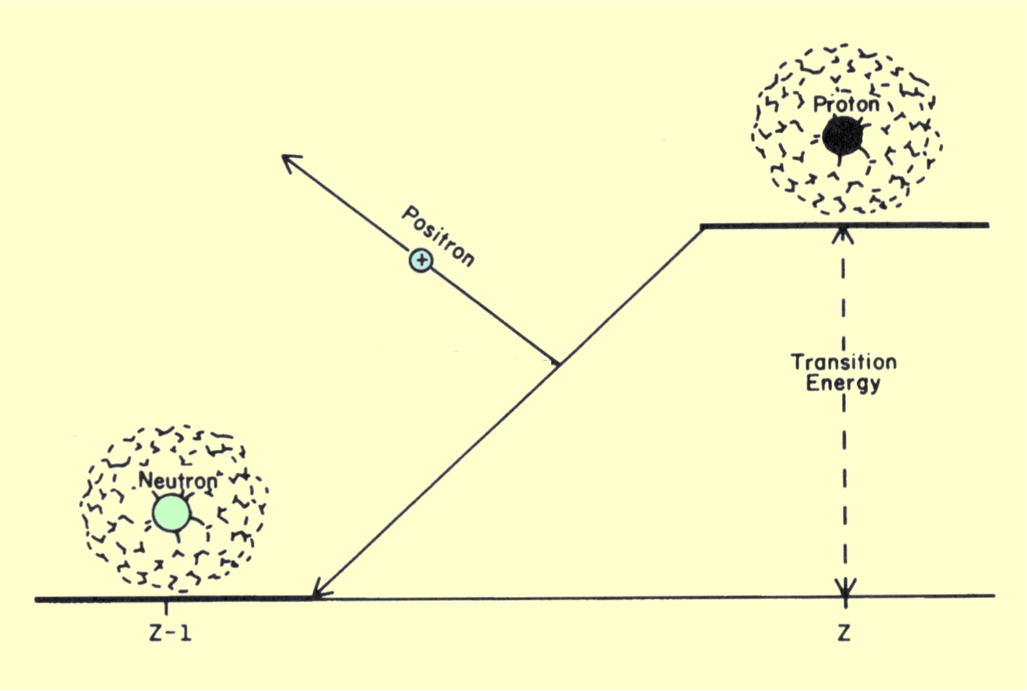
- Proton inside the nucleus change into neutron and positive electron (β^+) = positron which is ejected from the nucleus with high energy

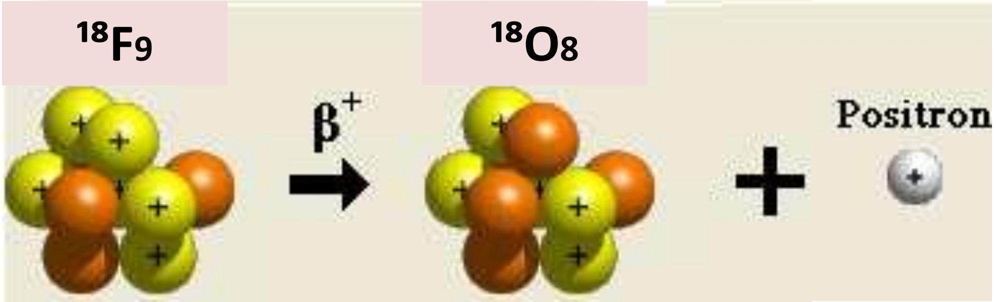
i.e. $\mathbf{p \rightarrow n + \beta^+}$

- So that:

Z is ……………

A is ……………





N.B: The product nucleus is usually excited

It loses this energy (immediately or after some time) in the form of γ ray (with energy specific to the parent nucleus)

B- Process of k-electron capture:

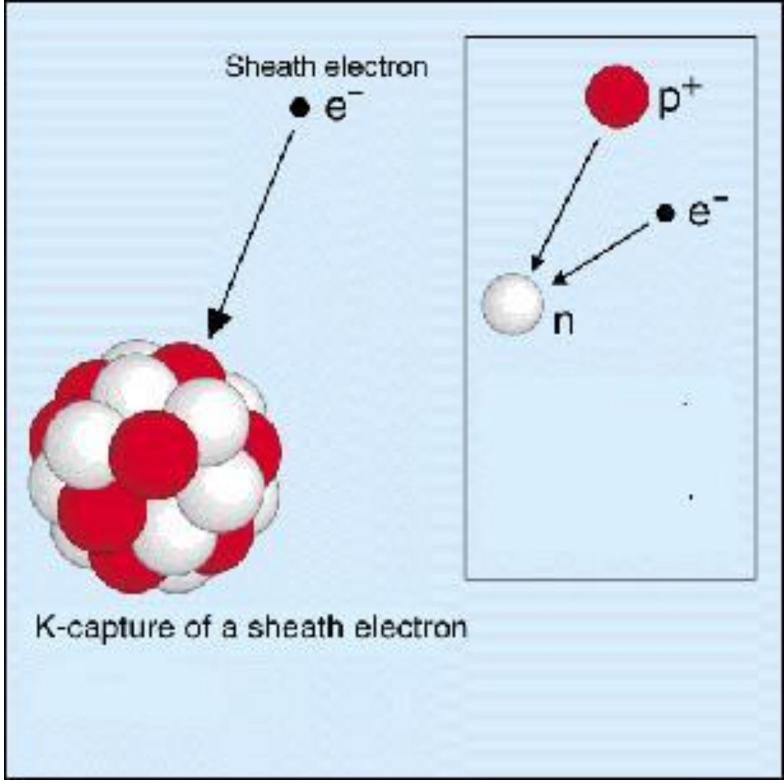
- The nucleus capture a k-shell electron which will unite with a proton to form neutron

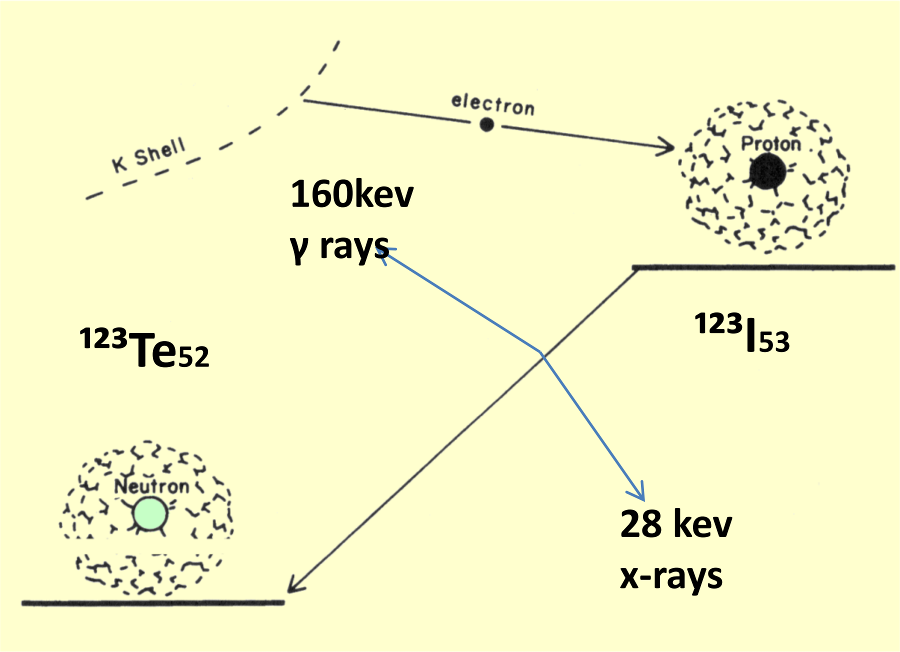
i.e. p + e → n

- K- characteristic x-ray will be also emitted (why?)
- Gamma rays may be also emitted if the daughter nucleus is in excited state
- So that

Z is ………………..

A is ………………..

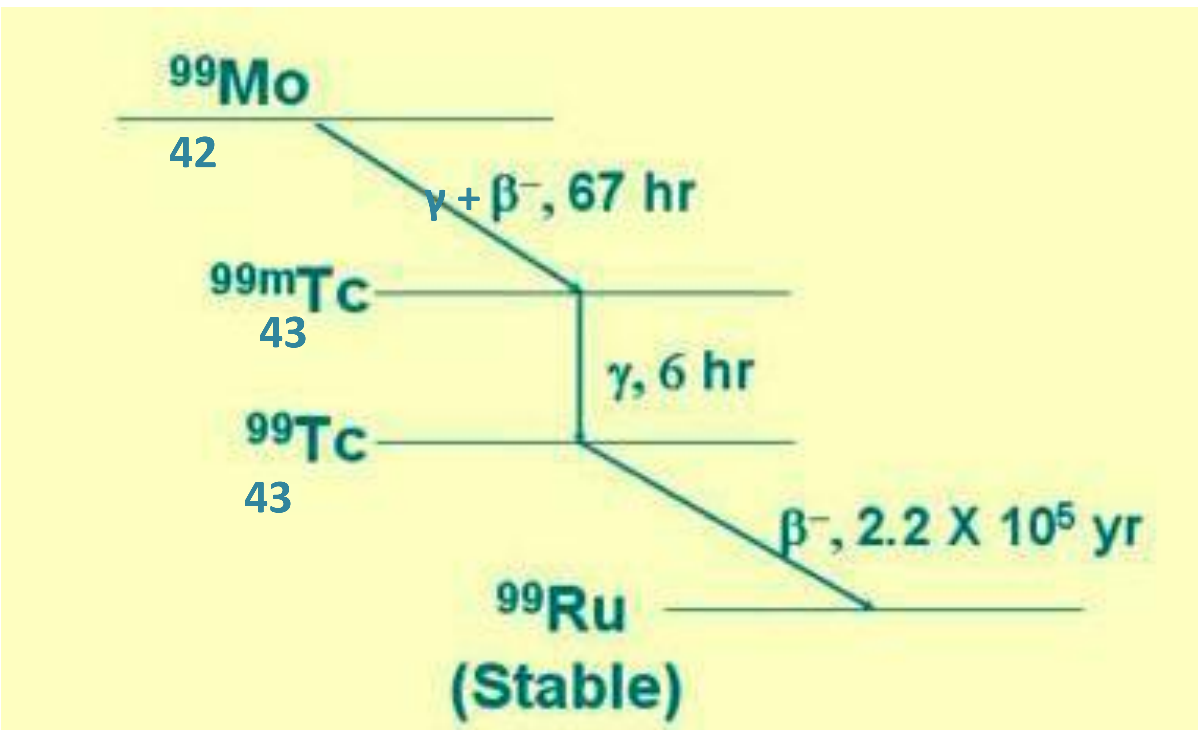




3-Isomeric transition:

An excited (metastable) nucleus decay to a more stable one with emission of gamma ray <u>only</u> with certain energy (specific to the parent nucleus)

Example:



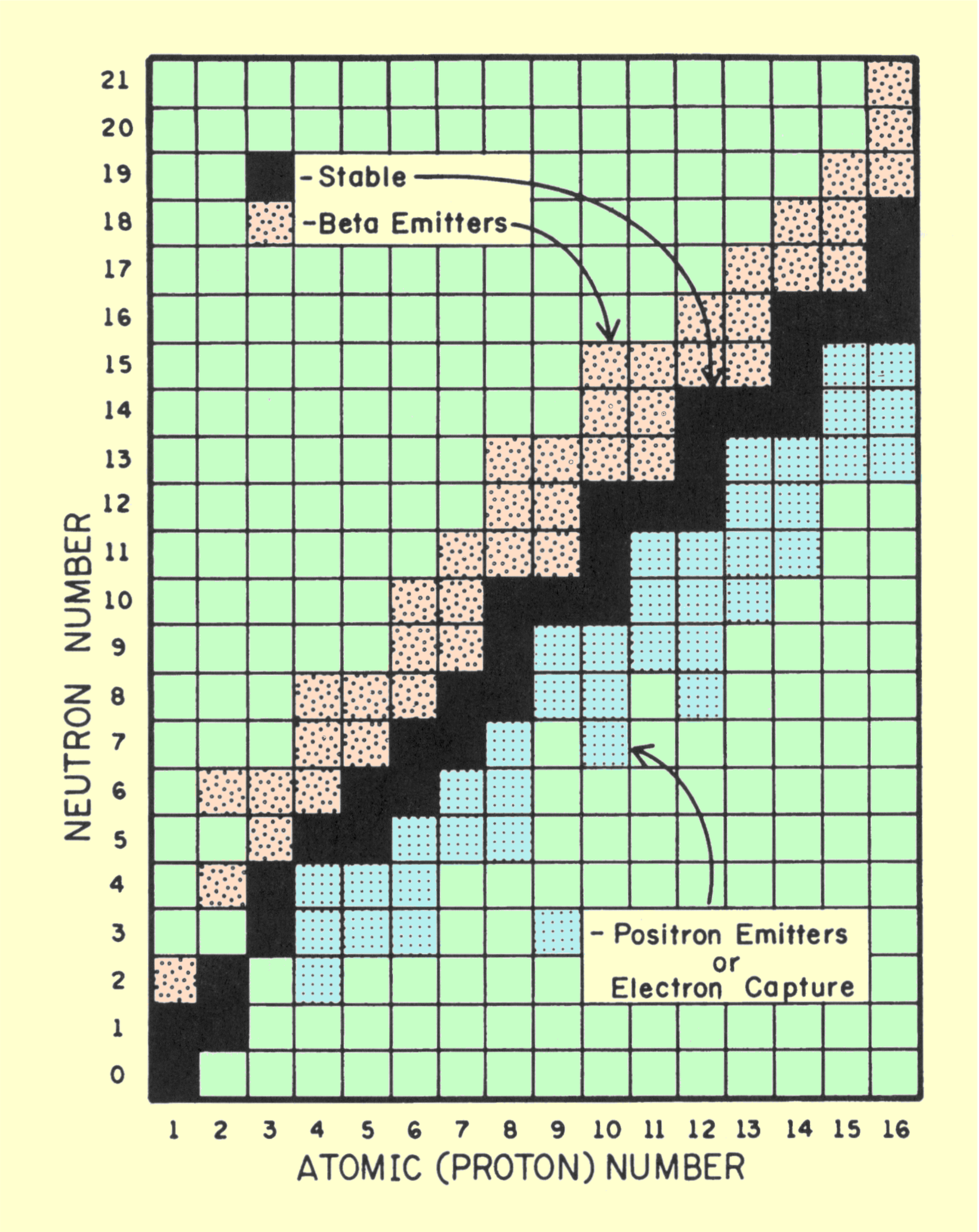
Note that:

1)Energy of gamma rays produced in this example = 140 kev

2) Tc^{99} and Tc^{99m} are isomers i.e. have different energy state and half life , but otherwise indistinguishable

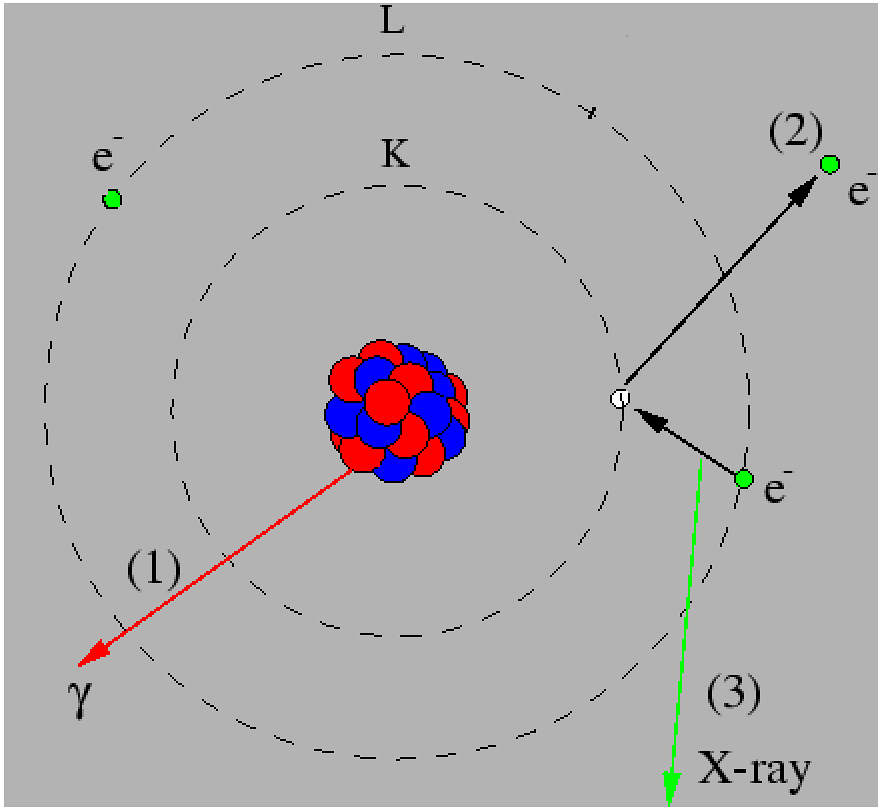
3) Mo-99 produce………, while Tc-99m produce ………

Summary of decay types



Internal conversion

- Photoelectric absorption of emitted gamma rays within k-shell of the atom
- Results :
  - 1- γ rays does not leave the atom
  - 2- characteristic x-ray and photoelectrons are produced
- Examples: I^{125} and I^{123}



Notes:

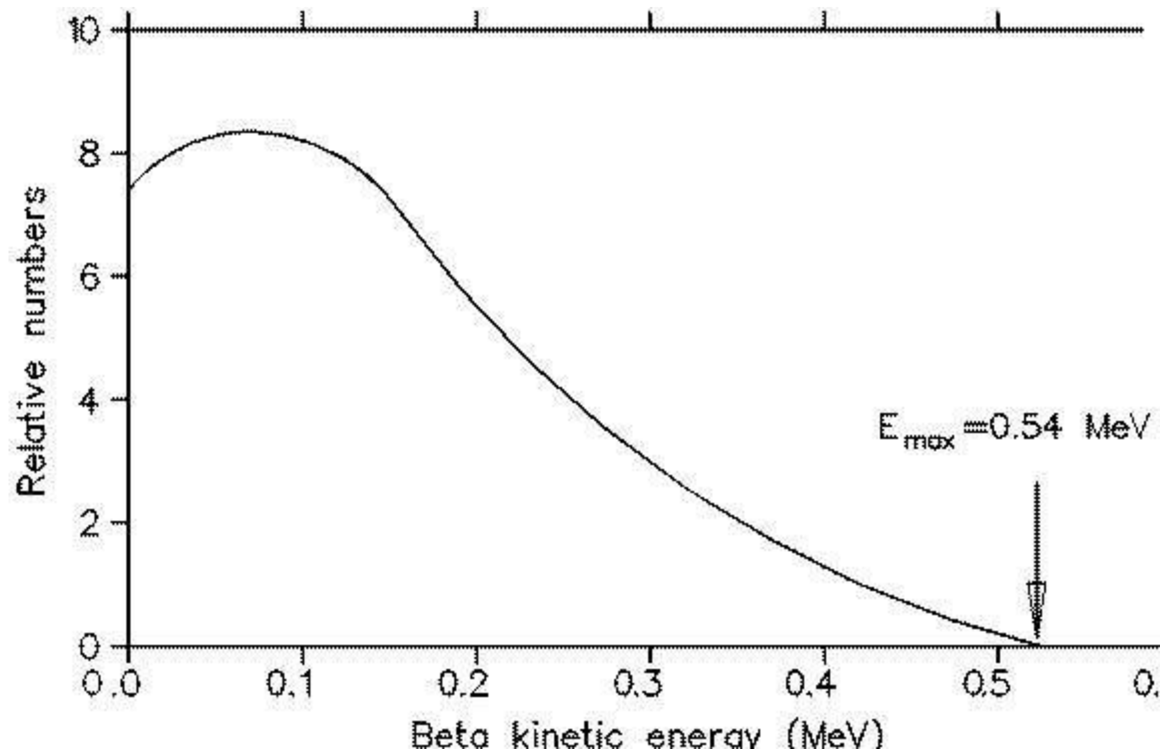
1- β particles are emitted with a continuous spectrum of energies up to E_{max} , which are characteristic to the radionuclide

2- β particles average energy is about $E_{max}/3$

3- β^+ and β^- interact with matter in the same manner as electrons (ionization and excitation)

i.e. directly ionizing

4- the most energetic β rays have a range of few mm in tissues



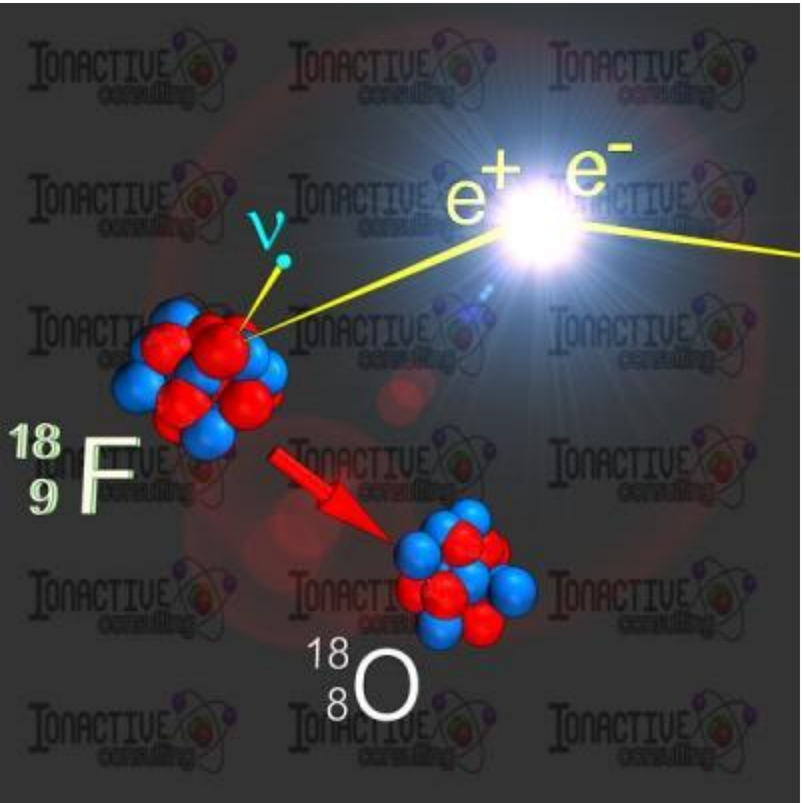
Positron annihilation

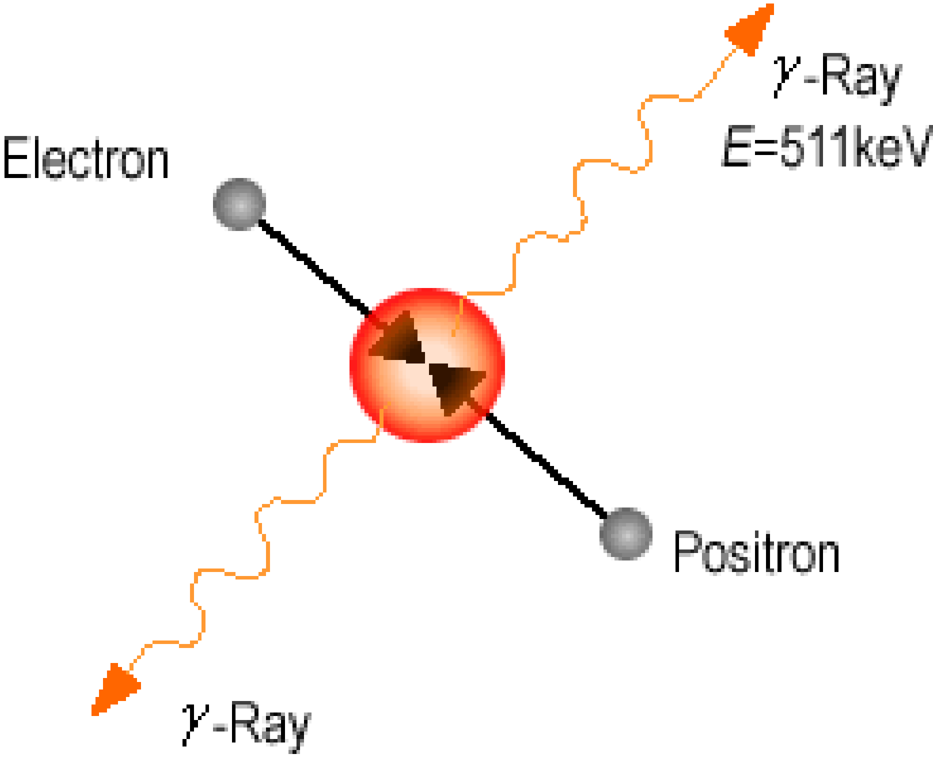
- Positron is antimatter and disappear quickly by process of annihilation:

1-it combine a nearby electron

2- combined masses of both are wholly converted to energy ($E=m.c^2$)

3-energy is emitted as two photons (511 kv each) , which travel in the opposite directions





Activity

- The method to measure quantity of radioactivity
- = decay rate = number of nuclei which will disintegrate per second
- Unit= Becquerel (Bq) = 1 disintegration / sec (very low activity)
- Old unit : curie (Ci) : 1mCi = 37 MBq
- Activity α number of radioactive atoms in the sample (why?)

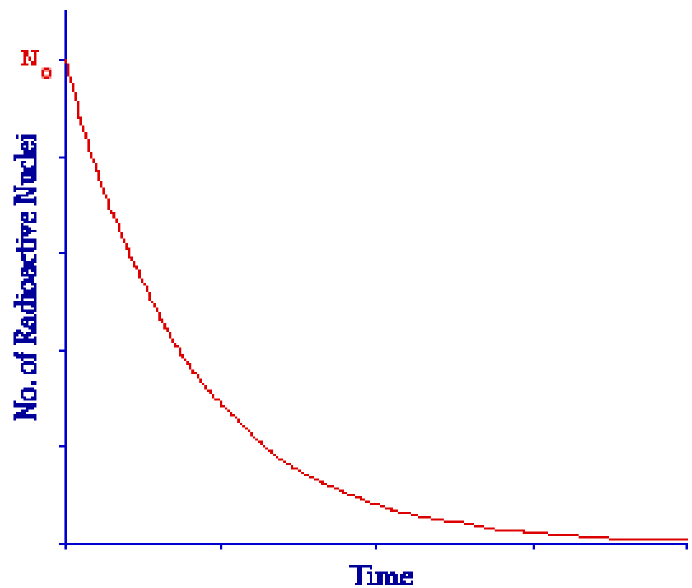
Count rate

- Quantity of gamma rays registered by detectors
- Count rate is less than activity (why?)
- But count rate α Activity

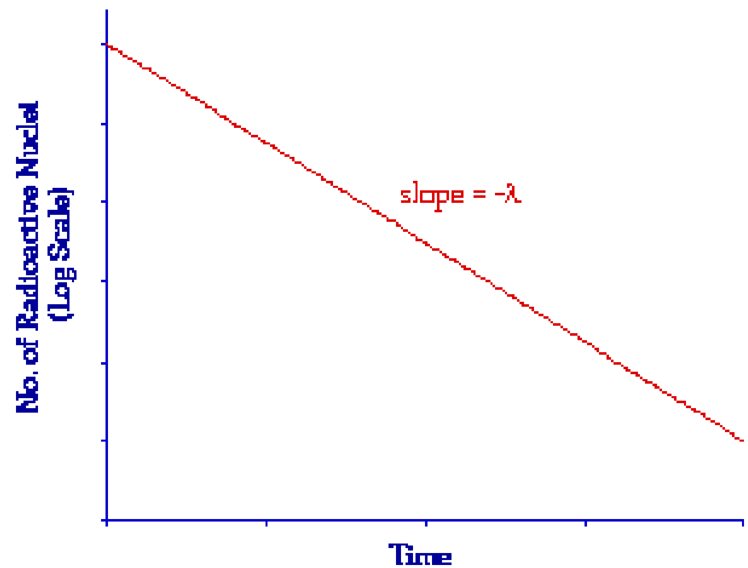
Fundamental law of radioactive decay

= exponential law:

- activity decrease in equal fractions in equal intervals of time
- Activity will never fall to zero
- Uses of the curve?



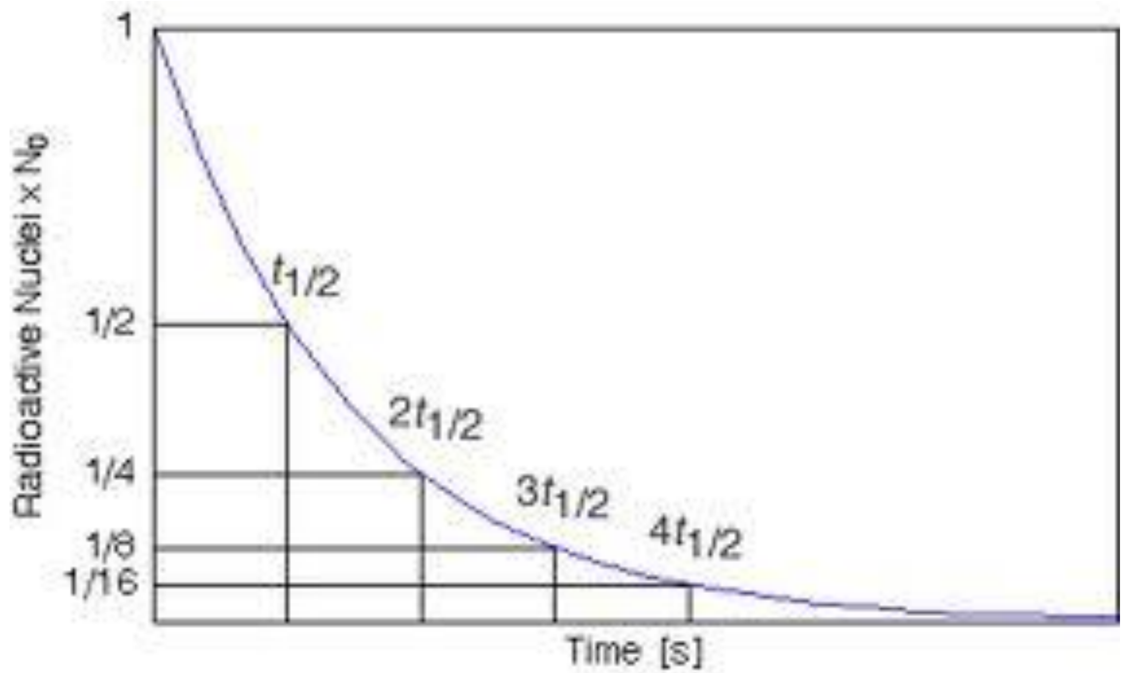
Linear scale → exponential curve



Logarithmic scale → line graph

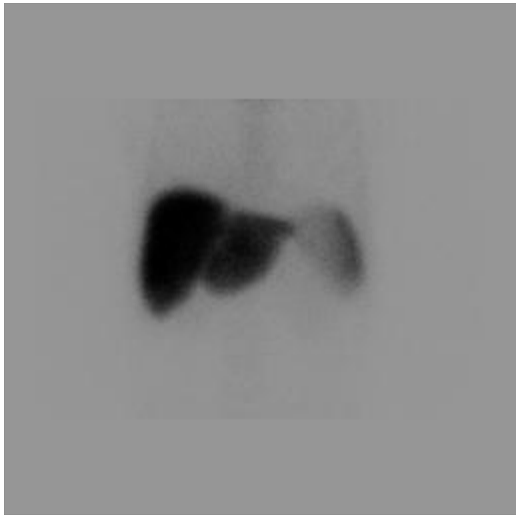
Physical half life (t½)

- time taken for the radionuclide activity to decay to half of its original value
- E.g. two t½ will decrease the activity by factor of ………………….
- Fixed whatever the activity
- The only factor which affect t½ is type of radionuclide
- Range from fractions of seconds to hundreds of years



Radio-pharmaceutical

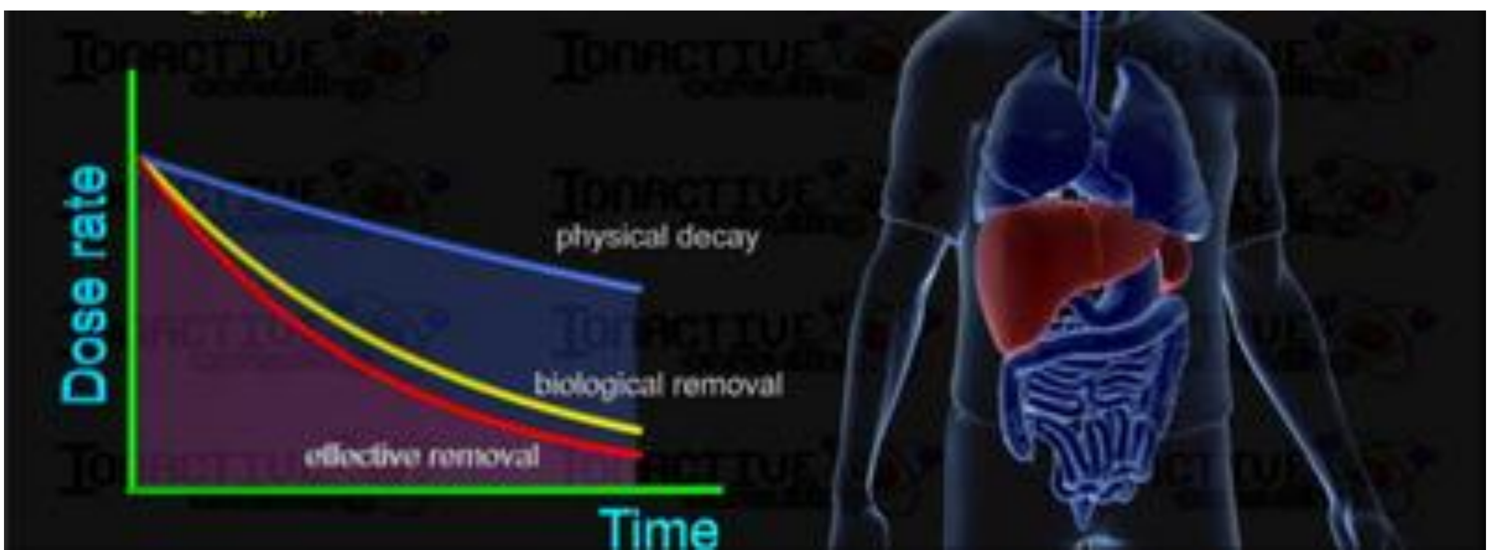
= radionuclide + pharmaceutical



- Radionuclide:
  - Radioactive
  - Role: signal the location of the radiopharmaceutical by emission of gamma rays
  - activity decay by physical half life
- Pharmaceutical:
  - its metabolic properties ensure that Radio-pharmaceutical is concentrated in the tissue of interest
  - Eliminated from these tissues by biological half life

Effective half life

- Dose (Radioactivity) of Radio-pharmaceutical decrease in specific tissue due to effective t½ , which result from the simultaneous effects of
  - radioactive decay (physical t½)
  - excretion (biological t½)
- Effective t½ = 1/ physical t½ + 1/ biological t½
- Effective t½ is shorter than the other two t½s

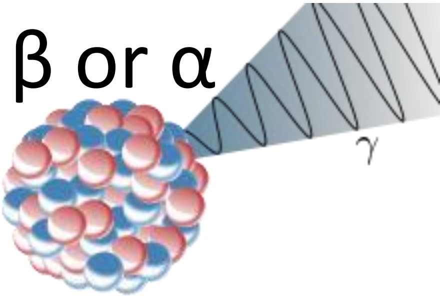


Desirable properties of nuclide

1- physical t½ of few hours (similar to the time from preparation to injection)

2- decay to a stable daughter or at least with very long t½ (why?)

3- decay by isomeric transition or electron capture producing γ or X-ray (but not β or α rays) why?



- 4- emission of gamma ray energy of 50-300 kev
  - If less → will not exit the patient
  - If more→ difficult to be collimated
  - ideally 150 kev
- 5- gamma rays with single energy (see PHA)
- 6- firmly attached to pharmaceutical at room temperature
- 7- available at hospital site
- 8-high specific activity (activity / unit mass)

Desirable properties of radiopharmaceutical

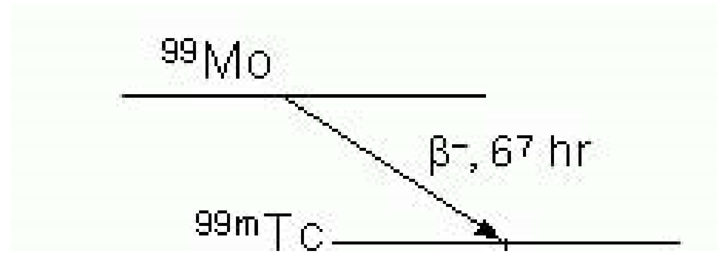
- Localize largely and quickly in the target tissue
- Eliminated by effective t½ = duration of examination (why?)
- Low toxicity
- Stable in vitro and in vitro
- available

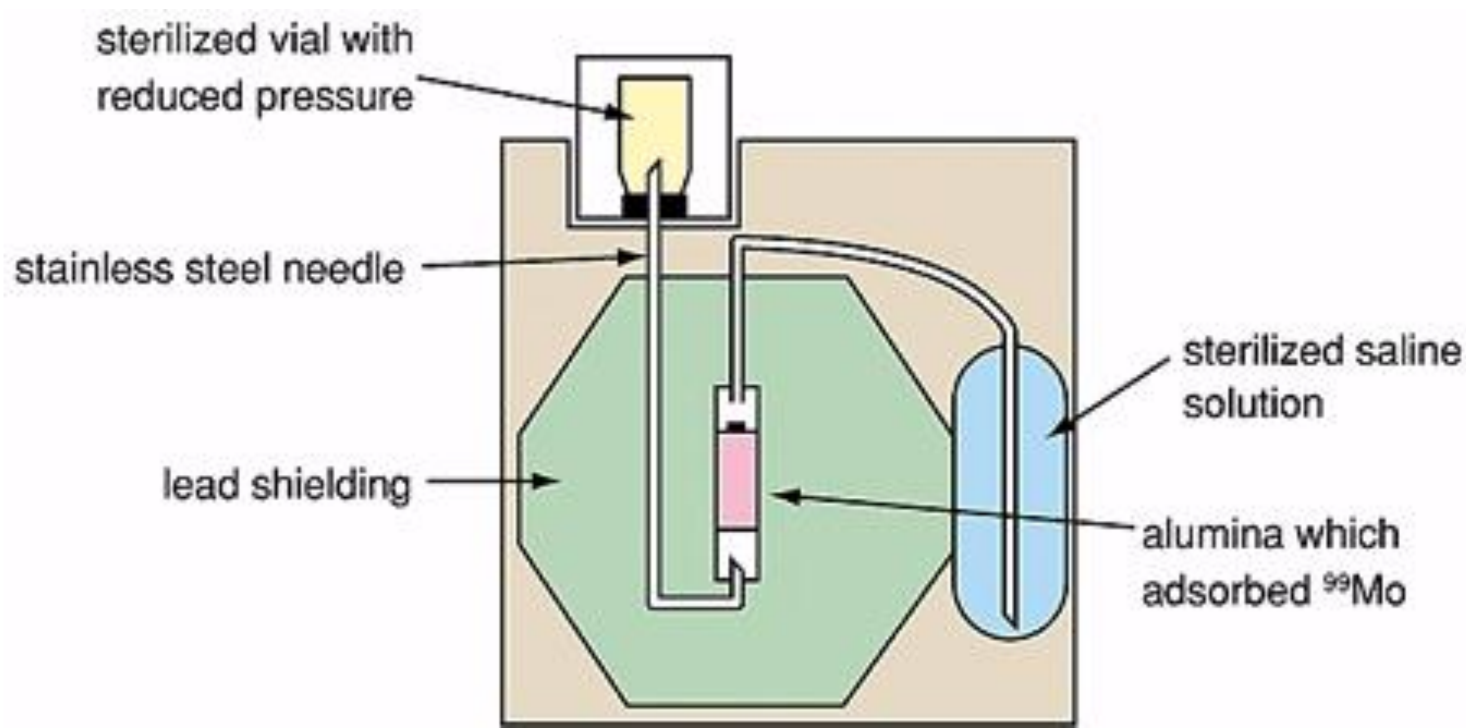
Tc^{99m}

- Used in 90% of radionuclide imaging
- Advantages :
  - Gamma ray energy = 140 kev
  - Relatively good spatial resolution of images because
    - Easily collimated
    - Easily absorbed in a thin crystal
  - Relatively Low noise of images due to reasonably large activity
  - Suitable t½ (6 h)

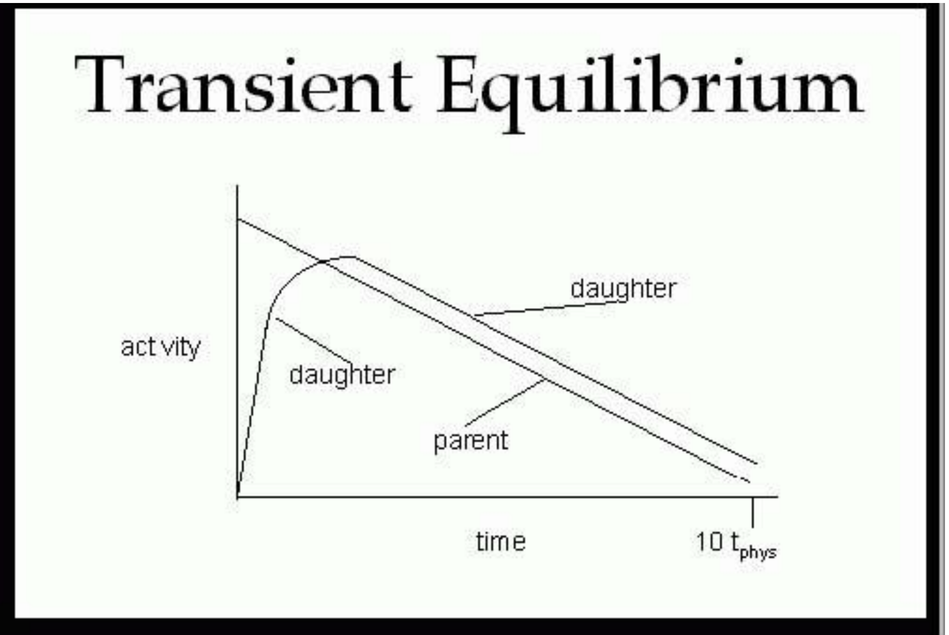
Tc^{99m} Generator

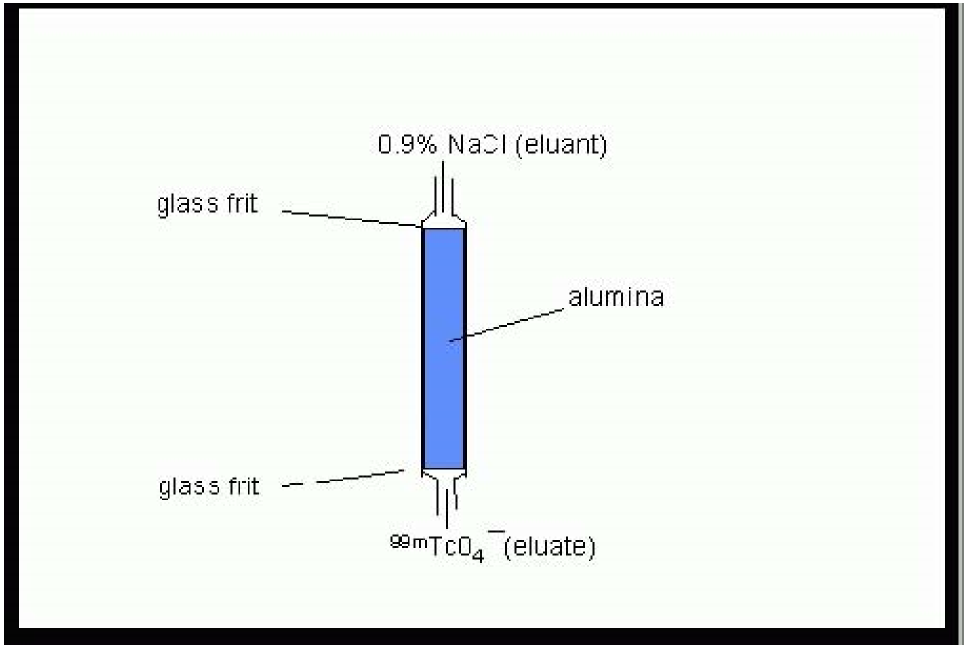
- Shielded with lead
- Parent Mo^{99}
  - produced by reactor
  - Disintegrate by β^- decay into Tc^{99m}
  - t½ = 67 hours
  - is absorbed in exchange column of alumina beads



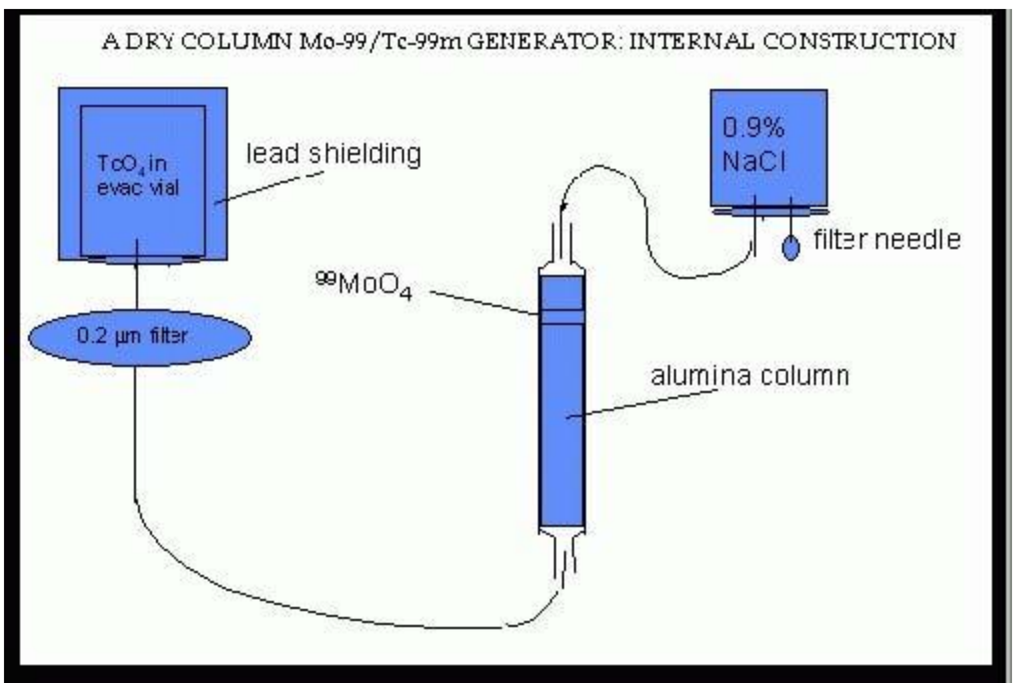


- When generator is delivered:
  - Activity of daughter Tc^{99m} is build up to its maximum (= activity of parent Mo^{99})
  - At this point It decay as quickly as it is been formed by the decay of its parent (with t½ of the parent) i.e. in transient equilibrium with its parent

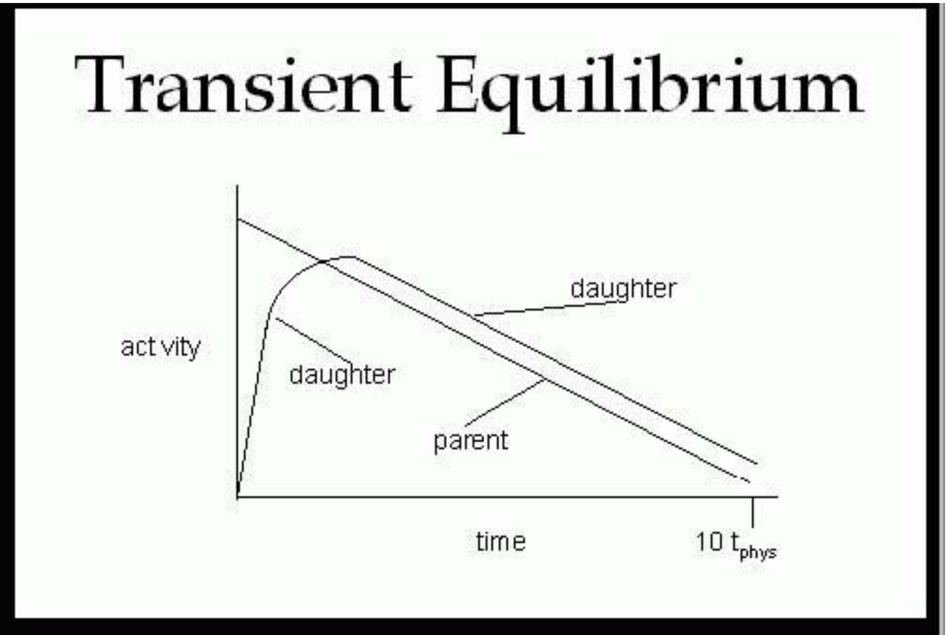


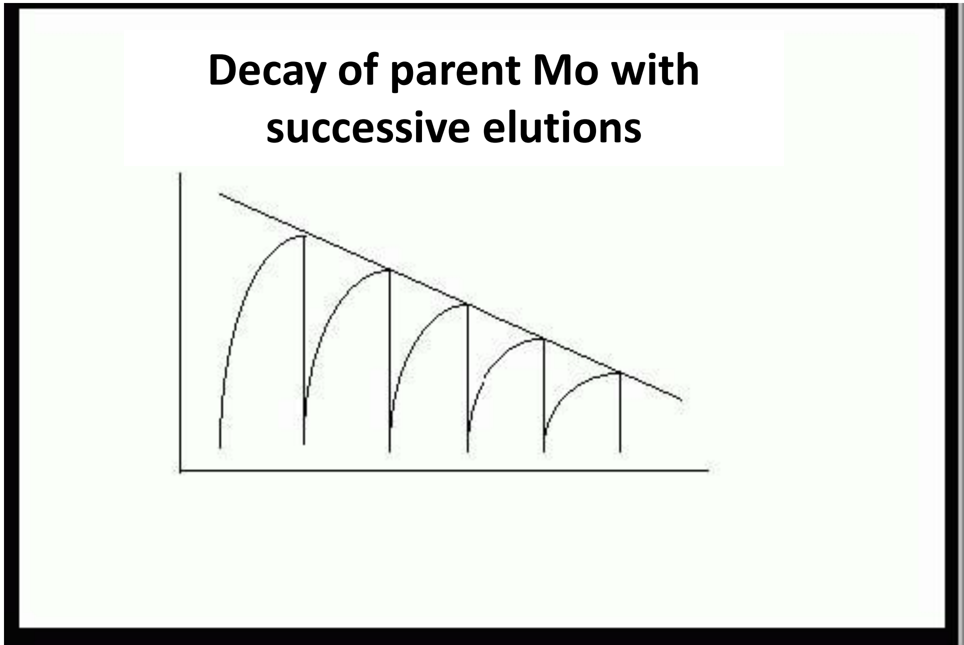


- Tc^{99m} is eluted (washed of the alumina column) with sterile saline solution flowing under pressure from reservoir → sodium pertechnetate
- The elution process :
  - Takes few minutes
  - Leaves behind the rest of Mo^{99} attached to column
- Eluent decay with its own t½ (6 h)



- After elution:
  - Increase again in the column with t½ of 6 hours
    - After 6 h →½ of the maximum
    - After 12 h →75 % of the maximum
    - After 24 h →grows to a new maximum (equilibrium)
- Elution:
  - Is made daily
  - Strength of successive eluents decrease with time (with decay of Mo)
  - →after a week the generator is replaced and the old one is recycled





Uses of Tc^{99m}

1) as sodium pertechnitate:

- Thyroid scan
  - Tc-99m is trapped by thyroid but not fully metabolized)
- Meckel's diverticulum localization
  - uptake by gastric mucosa)
- Salivary glands

N.B: Uptake by these tissues after due to similarity with iodide and chloride ions

2) as sodium pertechnitate after blockage of thyroid uptake by potassium perchlorate:

- Cerebral blood flow
- Testicular imaging

3) Combined with other materials (radiopharmaceuticals):

- 99m-Tc MDP: bone scanning
- 99m-Tc HMPAO: Cerebral imaging
- 99m-Tc DMSA and MAG3: renal studies
- 99m-Tc iminodiacetic acids (HIDA): biliary system
- 99m-Tc labeled sulfur colloid and human serum albumin (particle size = 0.5 µm) : liver, spleen, and bone-marrow imaging..
- 99m-Tc macroaggregated Human serum albumin (MAA) 15-20 µm in size: lung perfusion scanning.
- 99m-Tc DTPA: kidney and lung ventilation scanning
- 99m-Tc labeled red blood cells – cardiac scanning
- 99m-Tc Sestamibi: myocardial perfusion agent

Other radionuclides

name	t½	γ ray	X-rays	B rays	e capture	production	uses	other
I^{131}	8 ds	364 kev		+ve		reactor	Thyroid imaging and ablation	cheap
I^{123}	13hs	159 kev	28 kev		+ve	cyclotron	Thyroid &renal	expensive
I^{125}	60ds	30 kev					Thyroid (old)	
Xe^{133}	5.2ds	81kev↓		+ve		reactor	Lung ventilation	Inert gas
kr^{81m}	13sec	190kev				Generator (parent = Rb^{81}has short t½→must be used the day it is delivered)	Lung ventilation	Inert gas inhaled mixed with air (generator eluted by compressed air)
Ga^{67}	78h	93,185, 300kev			+ve	cyclotron	Lymphoma and abscess	Bind plasma proteins
In^{111}	67h	173,247 kev			+ve	cyclotron	Labeled RBCs: abscess Labeled platelets: thrombosis	
Tl^{201}		80 kev			+ve		Myocardial perfusion (rest&stress)	Analogue to k
In^{113m}	100m	390kev				generators	As In^{111}	

Radionuclides used in PET

name	t½	γ ray	X-rays	B rays	e capture	production	uses	other
F^{18}	110m					cyclotron	PET	Used as 2-FDG
C^{11}	20m					Cyclotron	PET	
N^{13}	10m					Cyclotron	PET	
O^{15}	2m					Cyclotron	PET	
Rb^{82}	75s					Strontium 82 generator	PET, myocardial perfusion	

Notes about preparation of radiopharmaceutical

1- usually by simple mixing of radionuclide with pharmaceutical in room temperature

2- shielded syringes are used

3-under sterile conditions e.g. using laminar flow cabinet that admit entry of hands through a curtain of flowing air

4- surfaces are impervious(e.g. continuous floors)

5- automated synthesis devices are used for PET radiopharmaceuticals

- t½ is short→ needs rapid preparation
- ↓staff radiation exposure

Quality control tests

Radionuclide purity:

- Definition: the ratio, expressed as a percentage, of the radioactivity of the desired radionuclide to the total radioactivity of the source
- Example: Tc-99m contaminated with Mo-99 → unnecessary dose
- Test: measuring any gamma radiation from Mo after blocking the gamma rays of Tc-99m by 6 mm lead

Radiochemical purity:

- Definition: the proportion of the total radioactivity in the sample which is present as the desired radio-labelled species
- Example: free pertechnitate within labeled technetium
- Test: chromatography

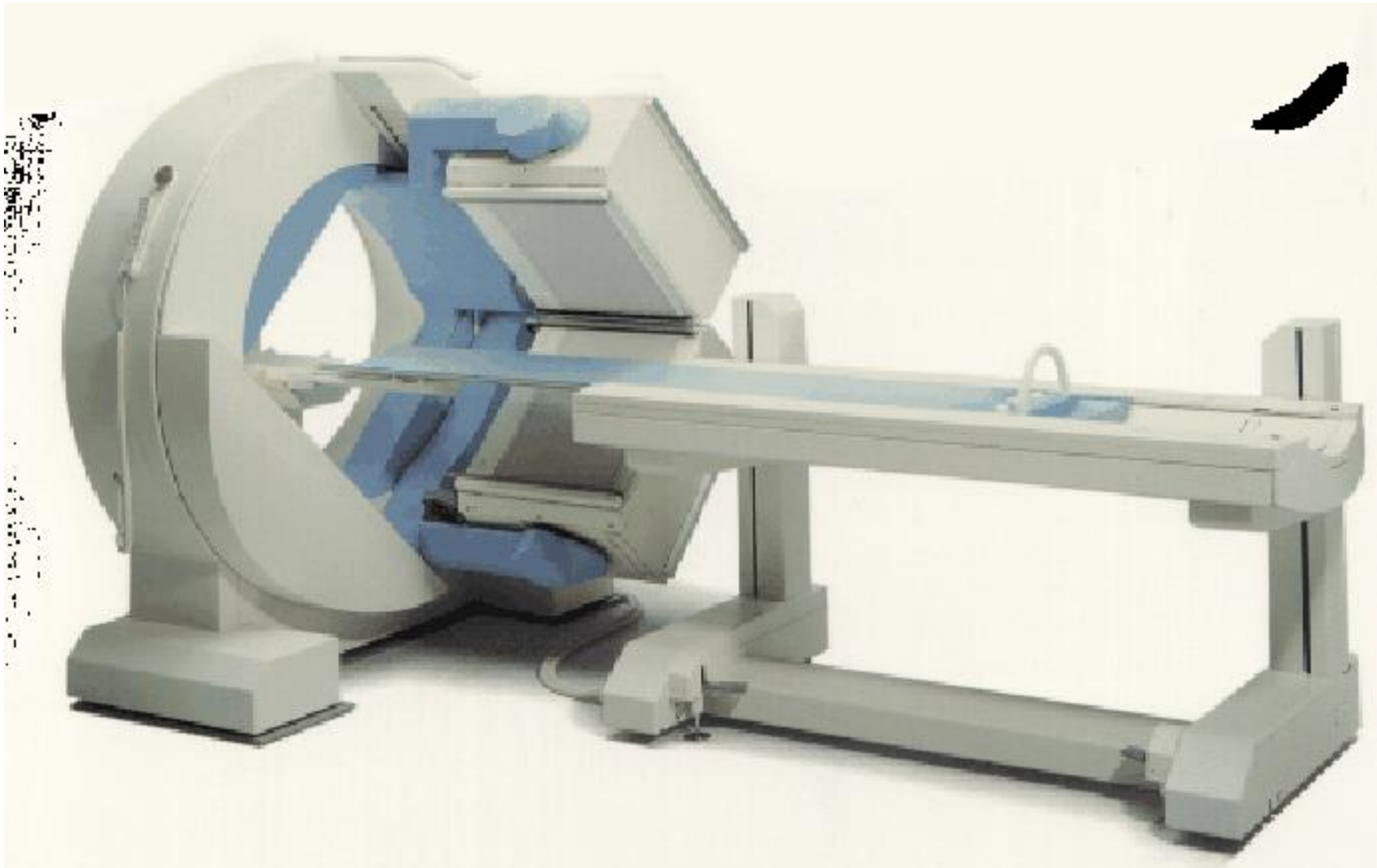
Chemical purity:

- Definition: The fraction of the total mass present in the stated chemical form
- Example: alumina impurities
- Test: spot colour test

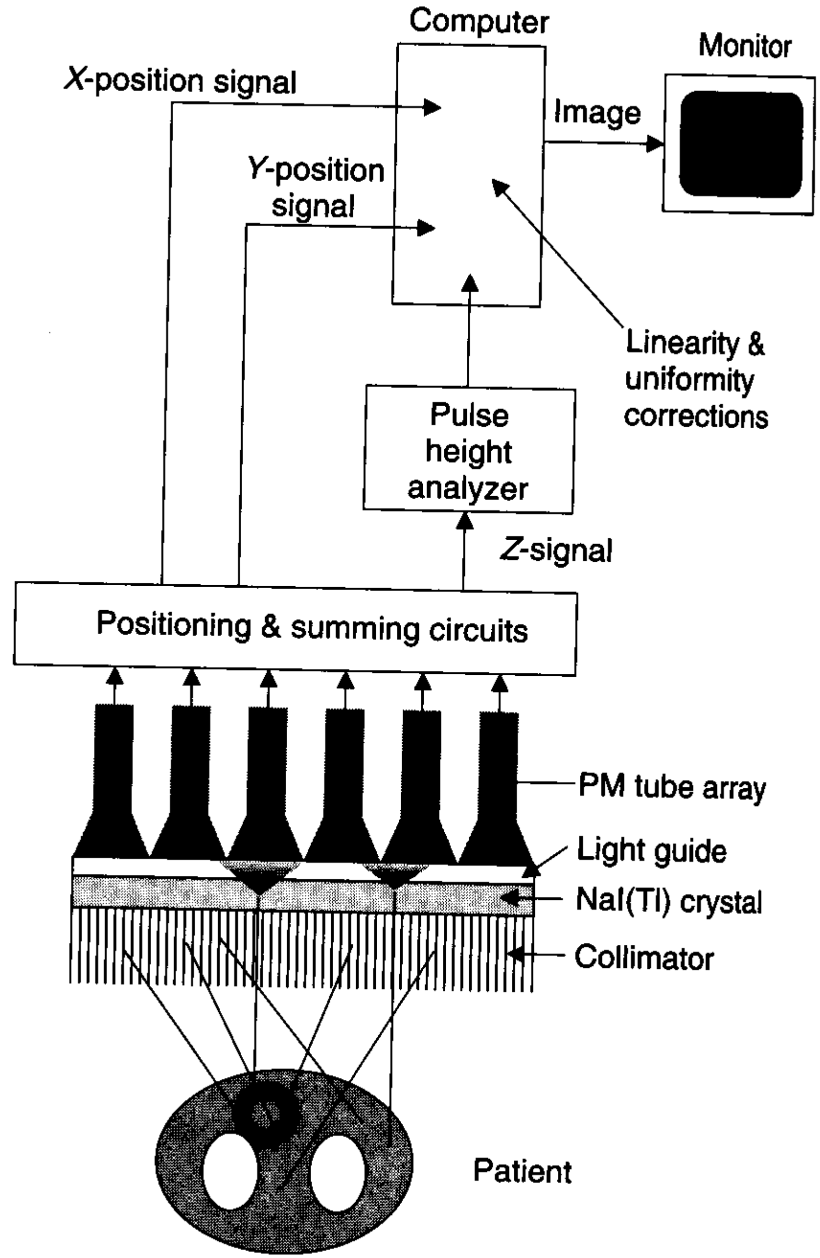
Sterility:

- results are available retrospectively

Gamma camera (plannar imaging)



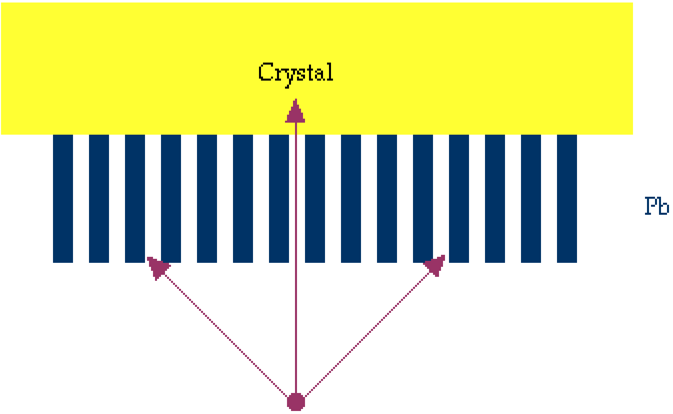
- The camera must have a heavy lead shielding to attenuate unwanted background gamma radiation

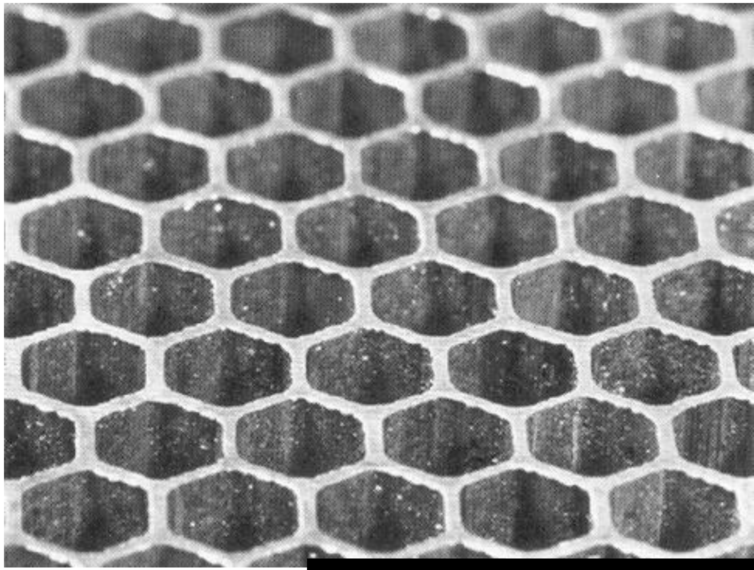


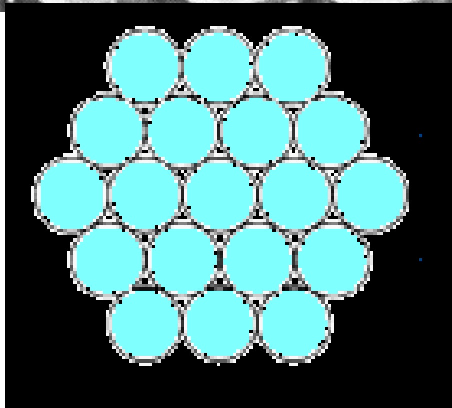
1) Multi-hole collimator

- Consists of lead
- Average Thickness: 25 mm
- Average Diameter : 400 mm
- About 20000 closely packed circular or hexagonal holes, each is about 2.5 mm in diameter separated by 0.3 mm thick septa
- Function: absorb most of rays that try to pass through the collimator obliquely

i.e. each hole accept γ rays from a narrow channel → help to locate radioactive source







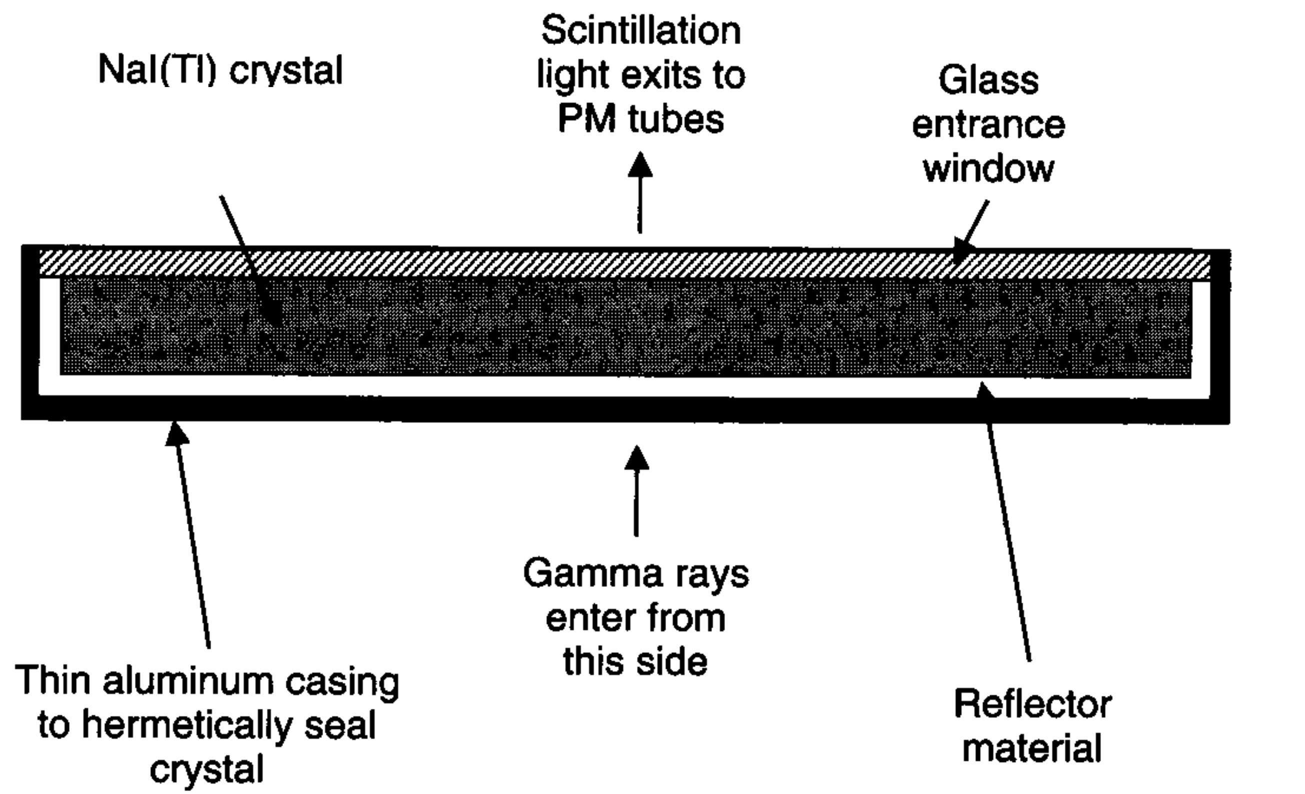
- Notes:

1- HVL of lead for Tc-99m = 0.3 mm

2- scattered radiation that pass through the collimator will have ↓ E → will be rejected later by PHA

2- The crystal

- Thickness: 9-12 mm
- Diameter: 500 mm
- Made of: sodium iodide activated with thallium NaI(Tl)
- Advantages: ↑Z (53) and density → absorb 90% of Tc γ rays by photoelectric effect
- Encapsulated in aluminum cylinder with one transparent face (towards the PMT) as it is fragile and easily damaged by temperature
- Coated also by reflecting titanium compound (except the transparent face)



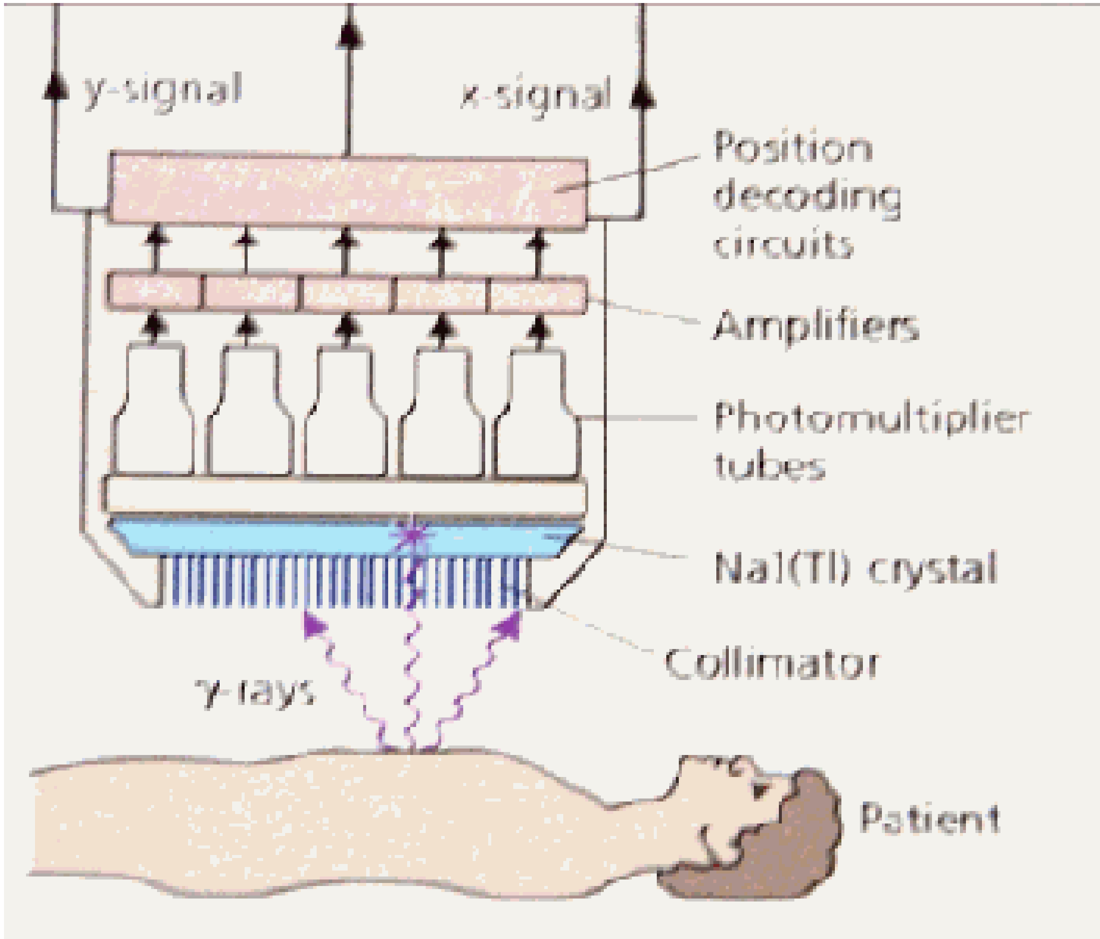
- Notes:

1- NaI(Tl) crystal absorbs only 30% of I^{131} γ rays (why?)

2- each γ photon produces 5000 light photon which travel in all directions , 4000 of them emerge from transparent face

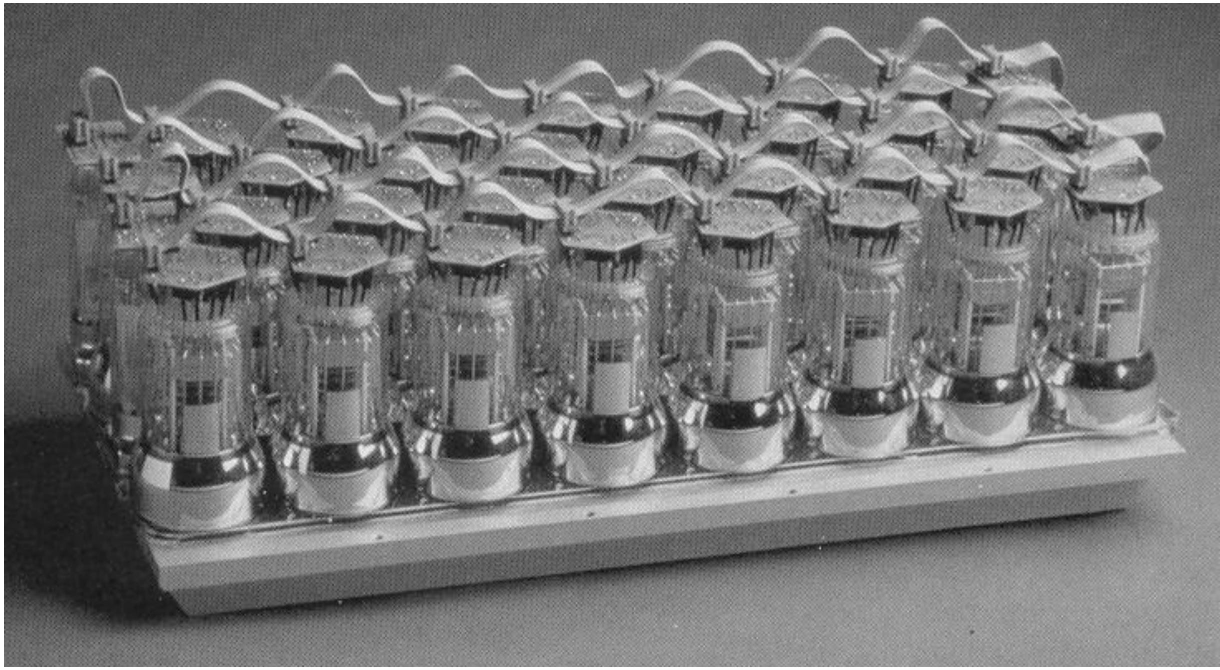
3-distibution of light leaving the face of the crystal depends on which collimator hole the γ ray passed through

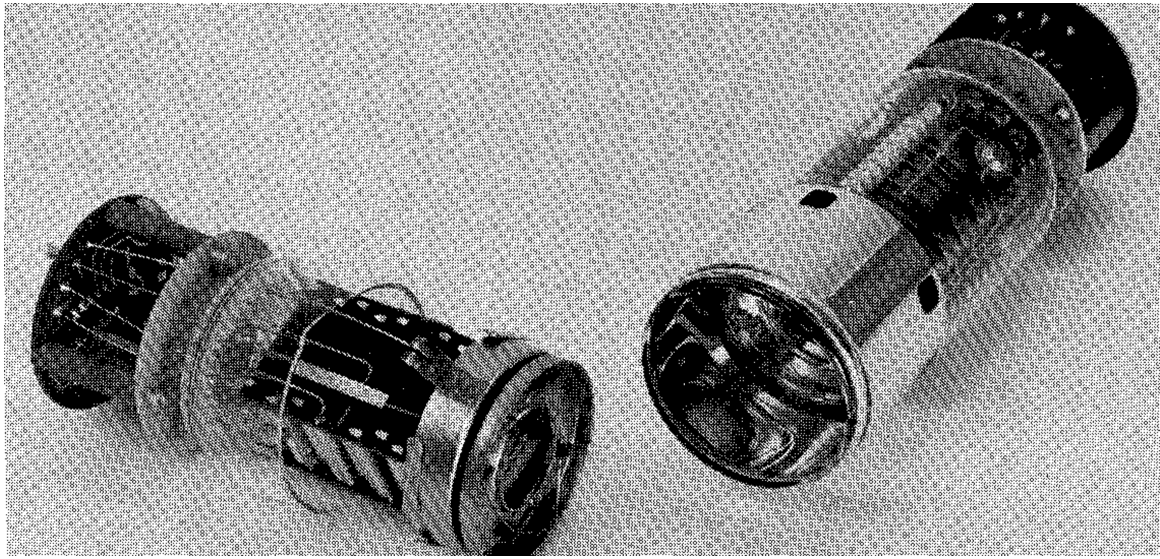
4- a light guide maximize transfer of light from the crystal to the photomultiplier tubes



3- photomultiplier tubes (PMT):

- About 91 matched photomultipliers , closely packed in a hexagonal array
- Each tube is contained in an evacuated glass envelop

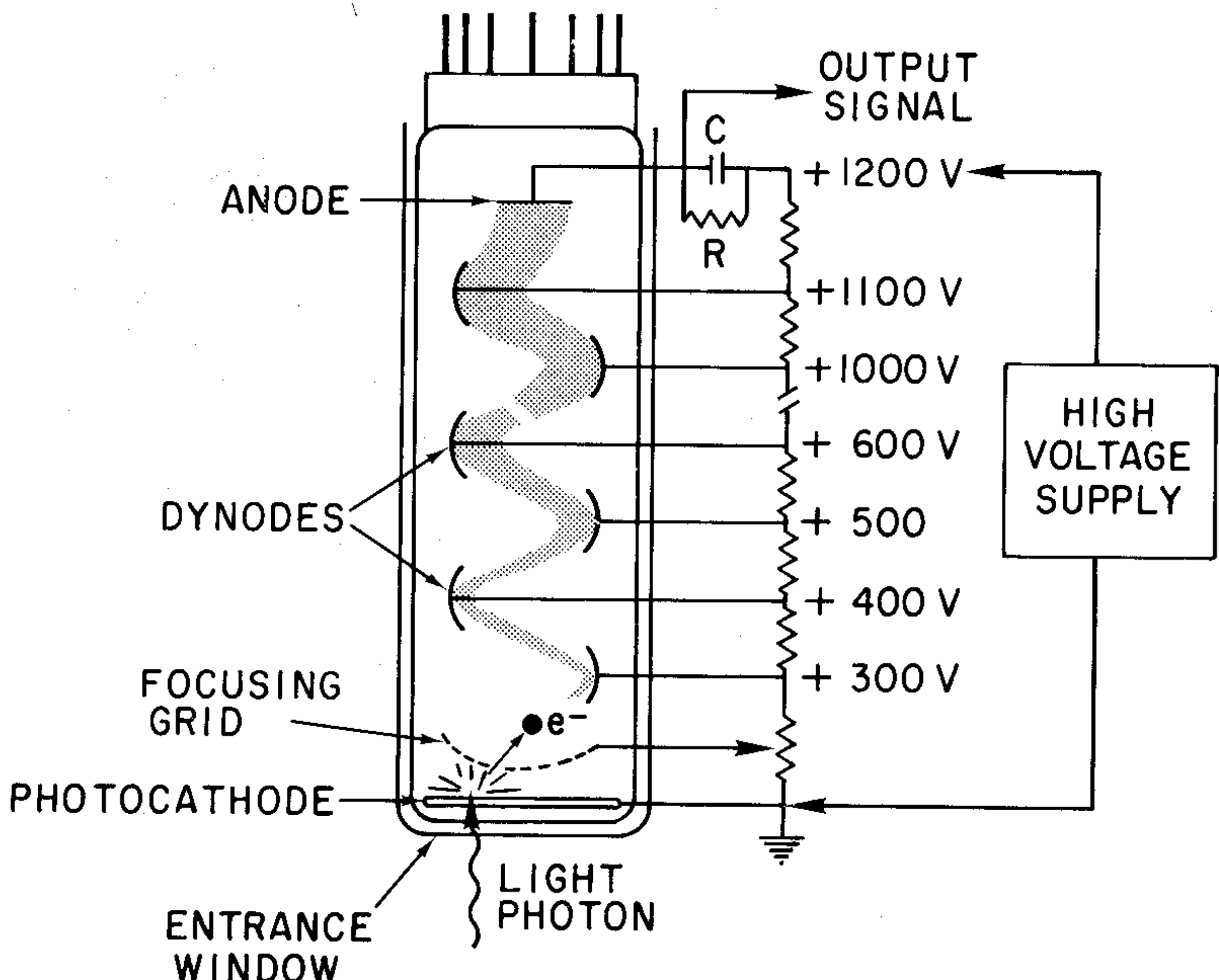




- PMT consists of:

A- photocathode:

Absorb the light photons, and emits photoelectrons (one electron per 5-10 light photons)



B- Dynodes:

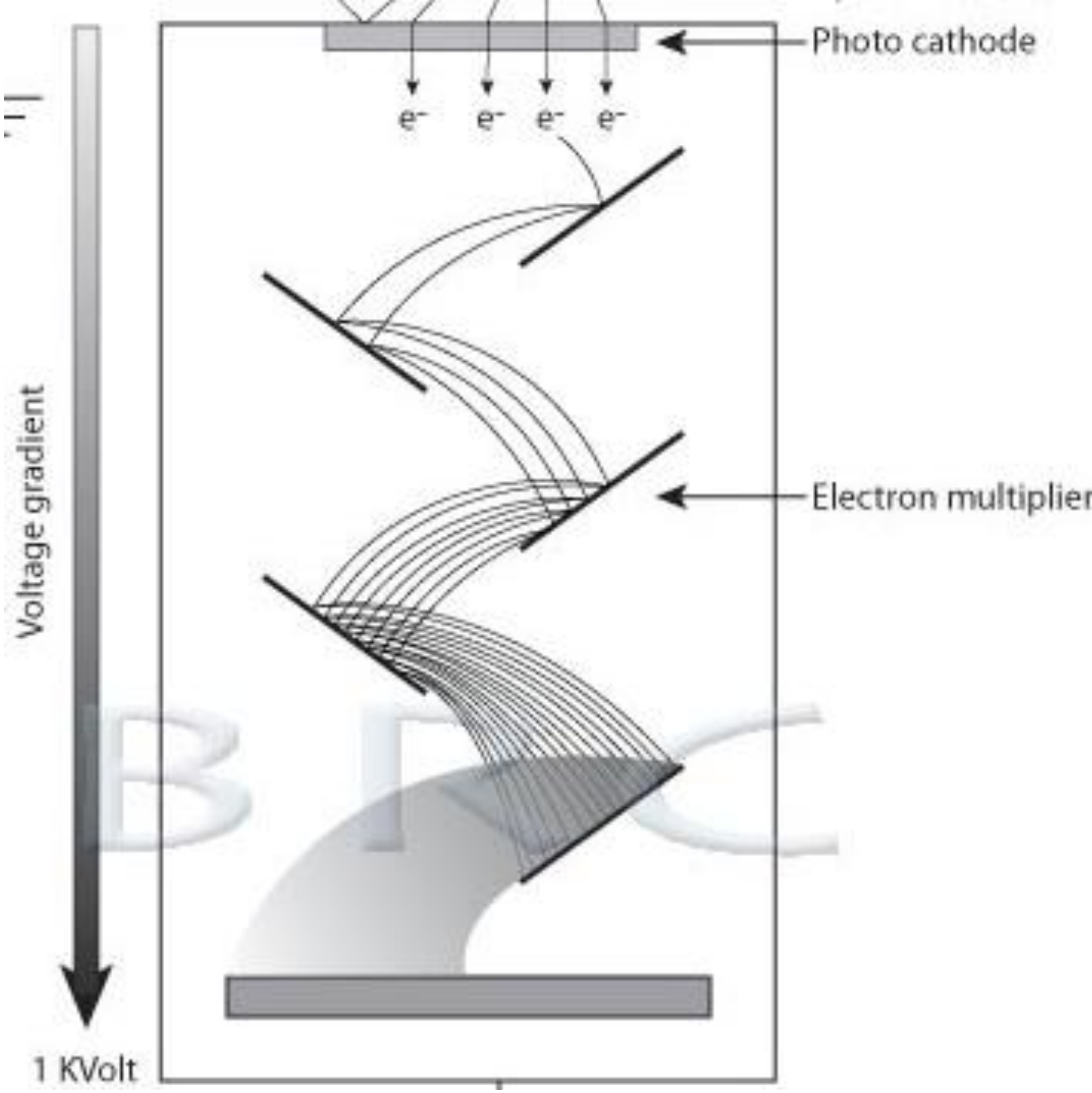
- On the routes of electrons towards the anode they impinge series of dynodes with progressively increasing +ve potential
- When 1 electron strike a dynode , it knocks out 3-4 electrons

i.e, after 10 stages , the electron are multiplied by factor of $4^{10} \rightarrow$ production of charge which is large enough to be measured electronically

- Amplification factor is very sensitive to changes in the overall voltage which is about 1kv (must be highly stabilized)

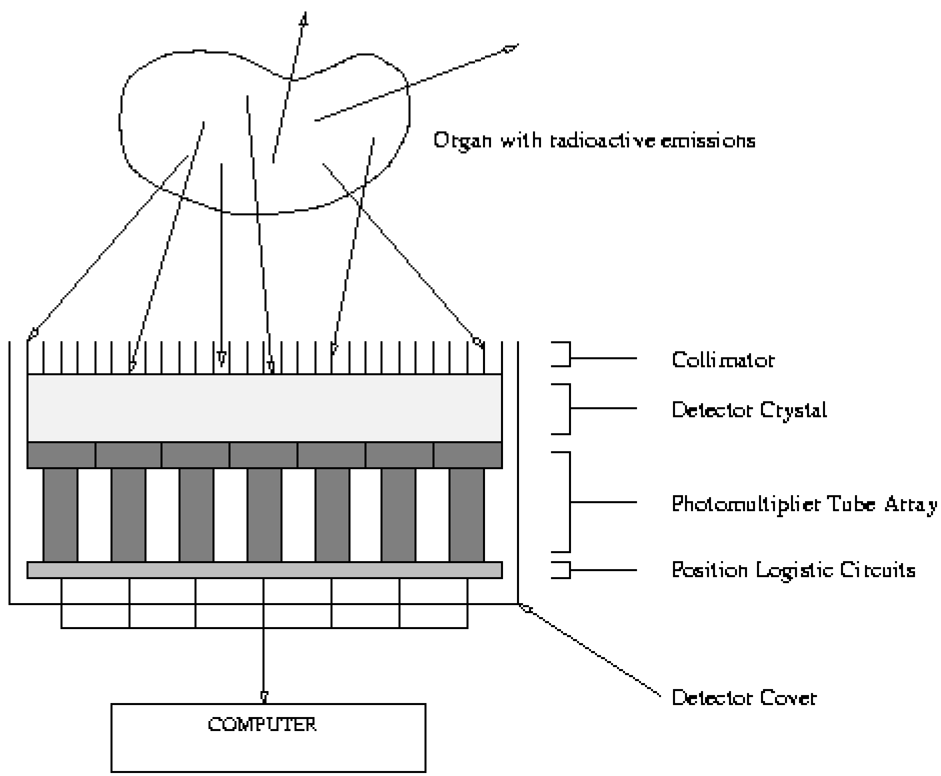
C- +ve Anode:

- Receive electrons and produce pulse



4- pulse arithmetic (position logic):

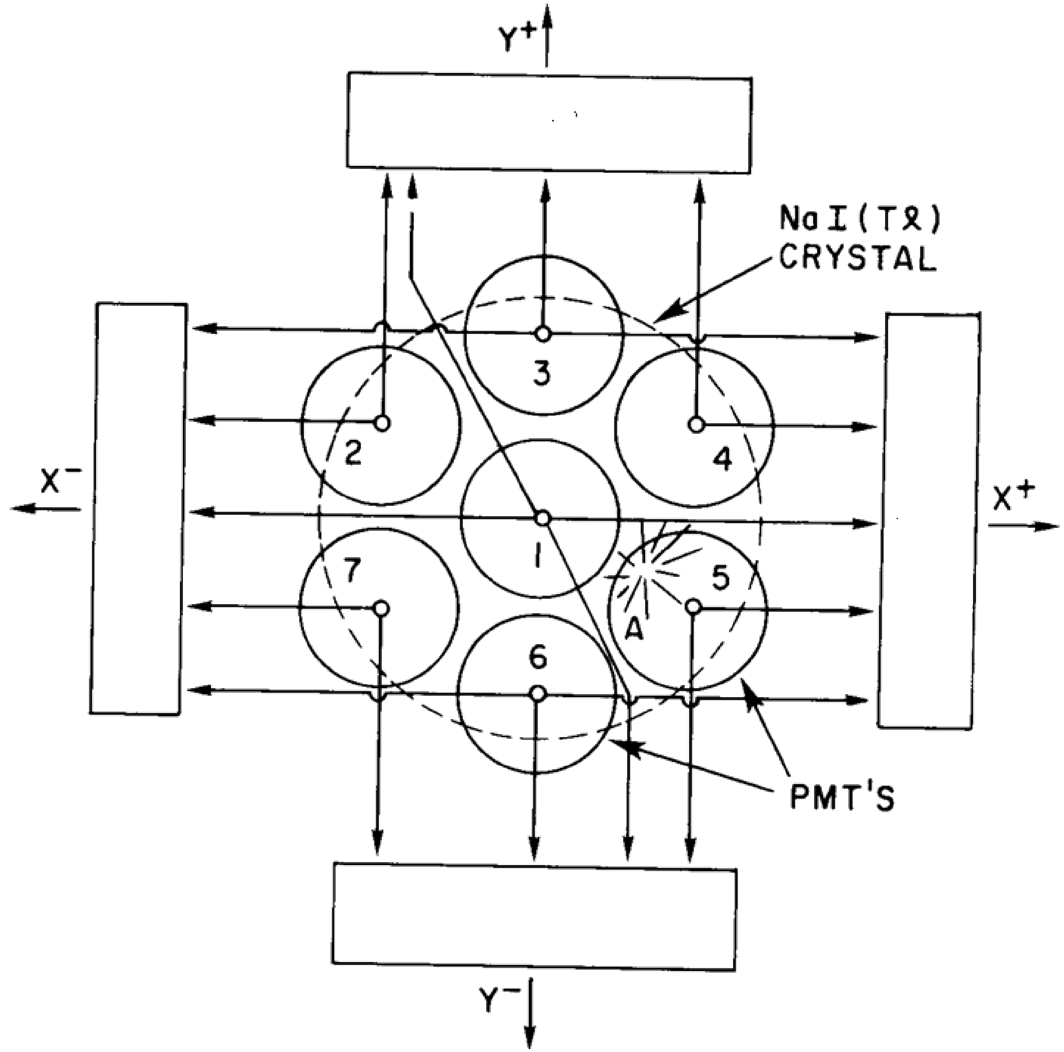
- Microprocessor chip
- combines the pulses from all PMTs (as if there is one large PMT) , and according to certain equations , it gives 3 types of voltage pulses:



A) X & Y pulses:

Horizontal and vertical pulses, coordinates of light flash in the crystal

i.e. determine the hole through which the γray has passed and so the position of radioactive atom in the body

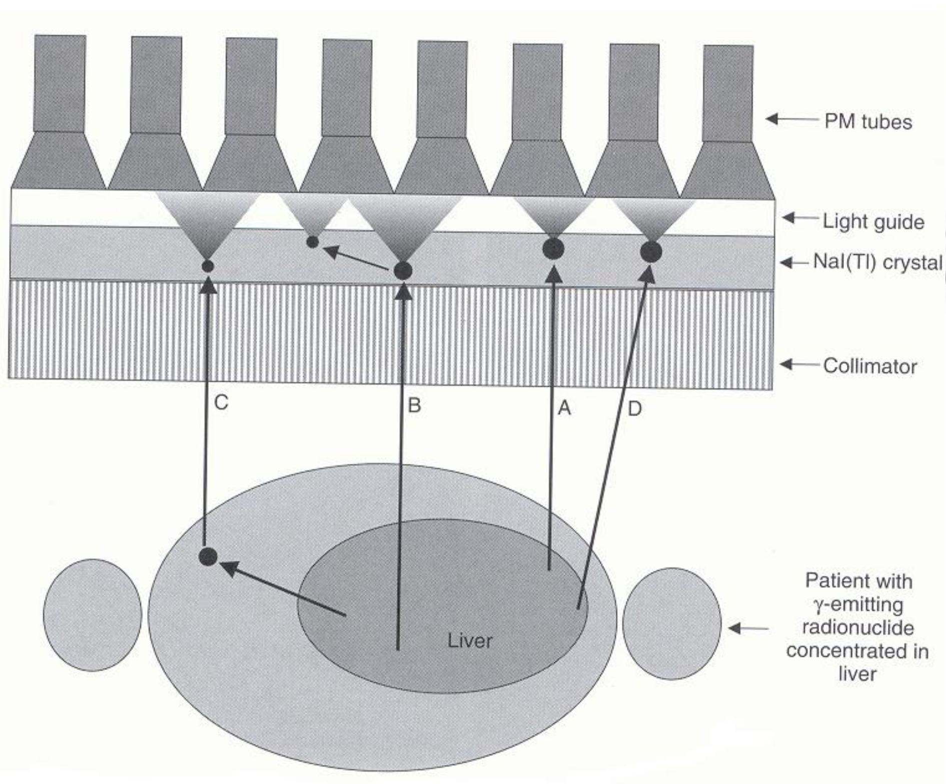


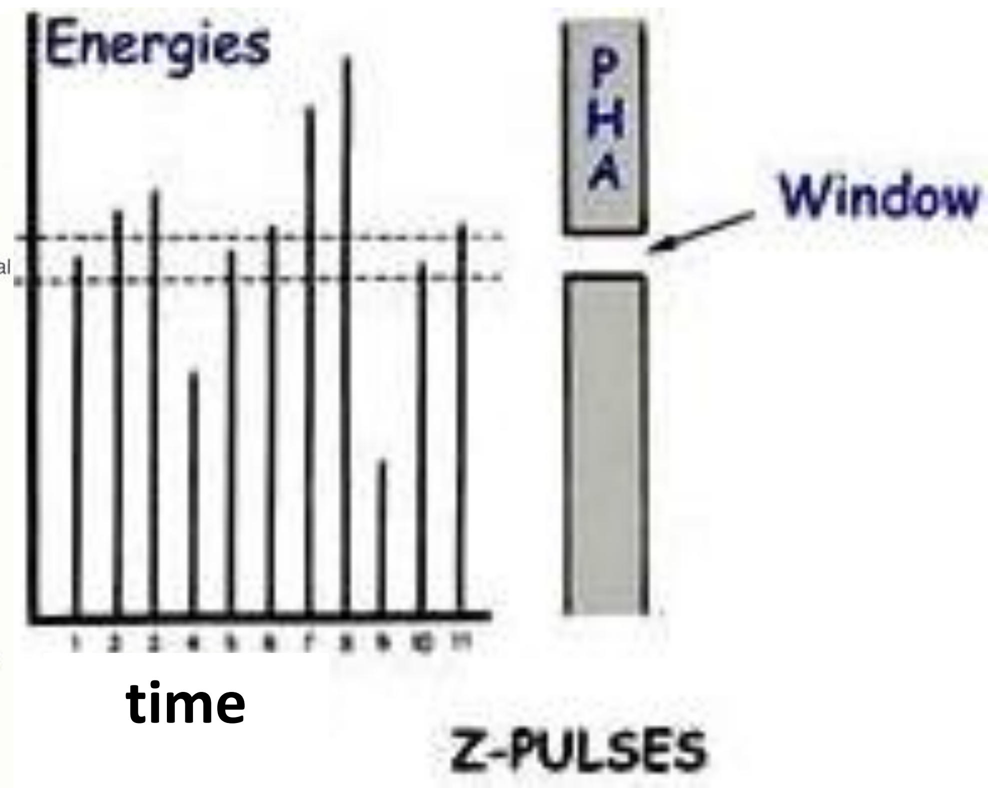
B) Z pulse:

Size (height) of Z pulse is proportional to γ ray energy absorbed by the crystal (in kev)

5- pulse height analyzer (PHA):

- Sources of Z pulse variation:
  a) Scattered γ rays in the patient
  b) Compton interaction with the crystal
- Function of PHA: set a window outside which the Z pulses are rejected (pulses inside PHA window are selected to form the image)
- Result: rejection of γ rays that were originated outside the line of sight of the collimator hole
- PHA window is set around 126-154 kev (why?)



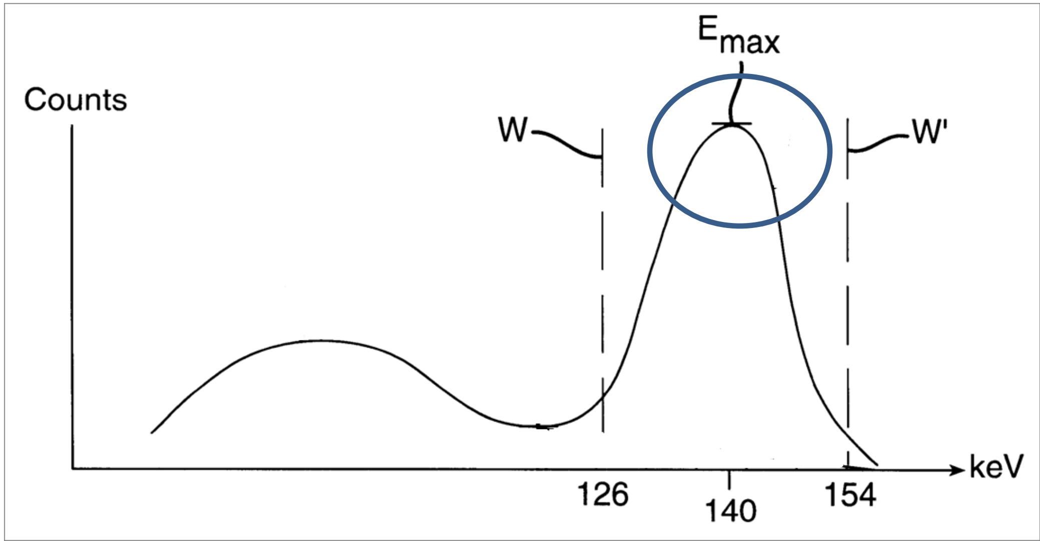


Pulse height spectrum:

- relative number of counts having various heights
- The spectrum is made up of the following:

<u>1- photopeak:</u>

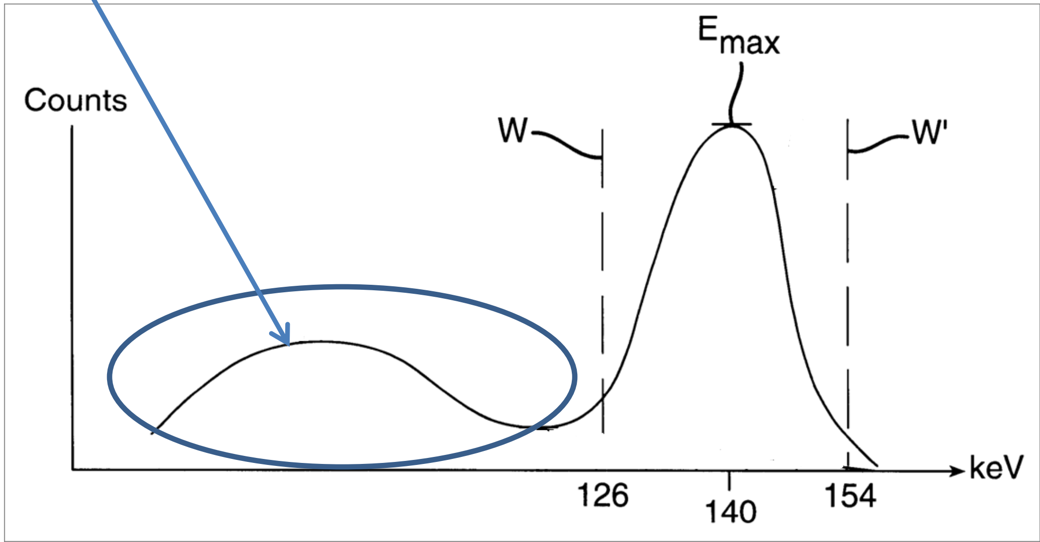
- Composed of pulses that were produced by complete photoelectric absorption in the crystal with no Compton scattering in the patient
- PHA window is usually Emax ± 10%
- Spread on energies in the photopeak is caused by statistical fluctuations in numbers of light photons and electrons produced



2- Compton tail:

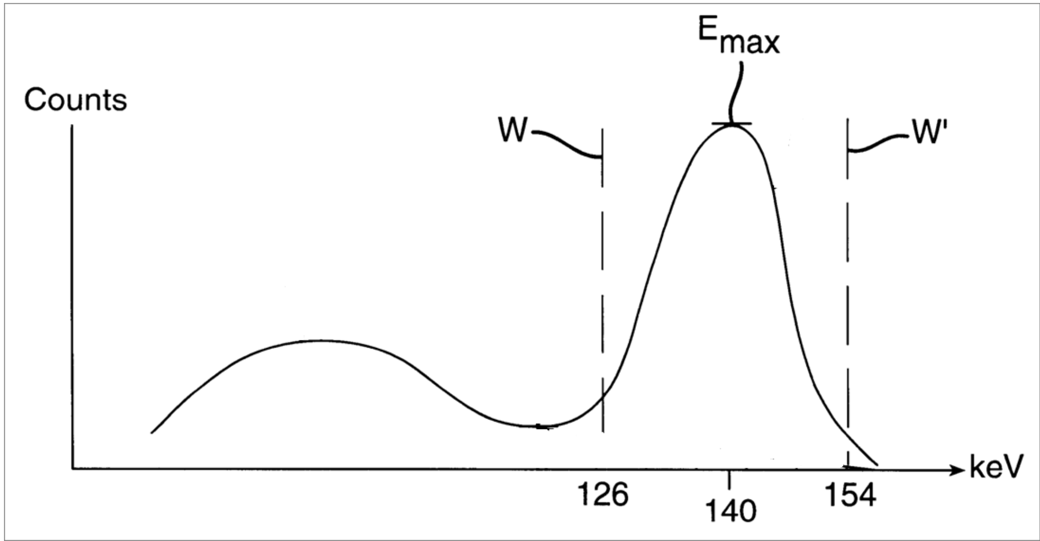
- Contains pulses of lower energies (produced by gamma rays hat suffered Compton effect in the patient or the crystal
- Rejected by PHA

N.B: Iodine escape peak: at 30 kev , due to some k-characteristic rays from iodine escaping from crystal



Notes:

- Causes of pulses with energies higher than photopeak (also ejected)
  1-cosmic rays
  2- as result of pulse pile up
- Some scattered γ rays which lost only 10% of its energy will pass through the window and degrade the image
- In case of Ga-67 or In-111 two or three windows must be set simultaneously



6- analogue to digital convertor (ADC):

Receive X , Y & Z pulses , and send them as digital data to the computer

7- the computer:

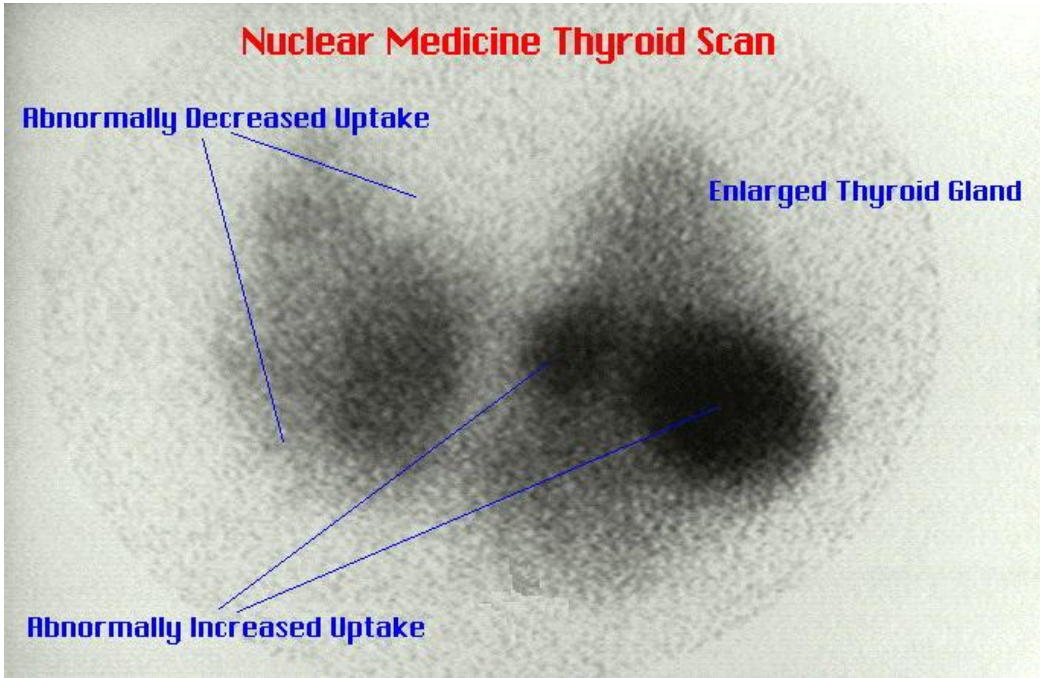
- Records each Z pulse as a count in a memory location corresponding to the X & Y coordinates (corresponding to a pixel in the image)
- Counts continue to build up in each location with time
- Once complete , the image is displayed on the monitor as a digital image in a matrix of pixels (e.g.128 x 128 matrix of 3 mm pixels)
- brightness of each pixel α number of counts stored in the corresponding memory location α number of γ rays ejected from the same area of the patient (activity of the tracer in this location)

- **Q. how long the collection of data must take?**

The patient continues to be scanned until total counts of 500000-1 million counts are acquired for each image frame

If more : the image will become uniformly bright i.e. all memory locations will become full (8-bit memory can hold ……… counts)

If less: noisy image



- Image displayed on the monitor can be manipulated (as any other digital image)

  Examples :

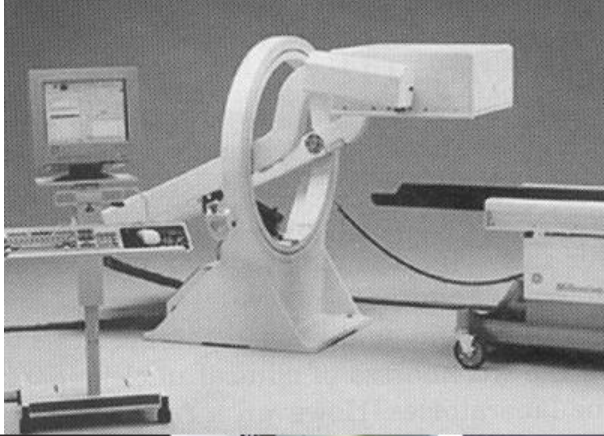
  – Windowing (enhance contrast)

  – Averaging (reduce the noise)

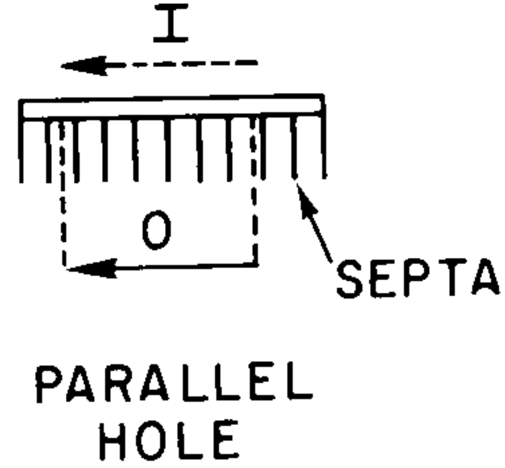
- Separate images of 2 radionuclides can be obtained in the same time by setting two different PHA windows (& one image can be subtracted from another)

Types of gamma camera

- General purpose camera: (as described above)
  - Field of view: 400 mm
  - Usually used for Tc studies
- Mobile gamma camera:
  - Field of view: 250 mm
  - Used in Tl cardiac scanning (easy to position &use in ICU)
  - 5 mm thick crystal (why?)
- Large field of view camera:
  - Field of view : 500 mm
  - Used in: bone and Ga imaging
- Scanning camera:
  - Camera head transverse along the long axis of the patient (to increase image matrix)

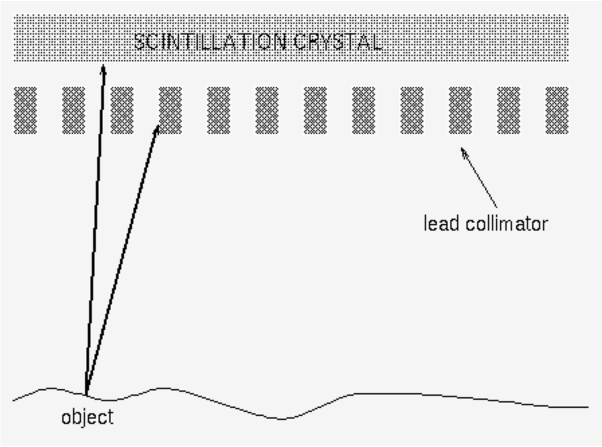


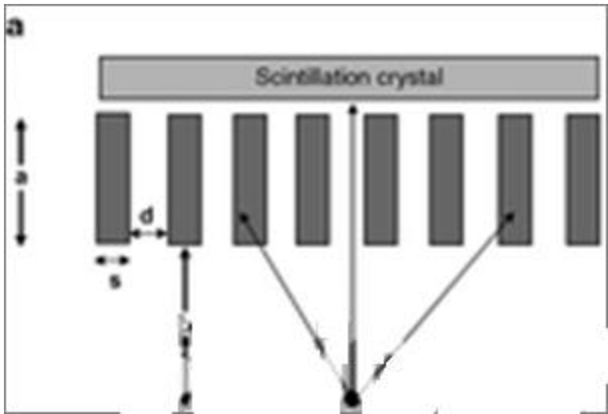
<u>**Types of collimators According to the holes**</u>



1- parallel hole collimator:

- Most commonly used with general purpose camera
- In air sensitivity are the same at all distances from the collimator face





2- divergent hole collimator:

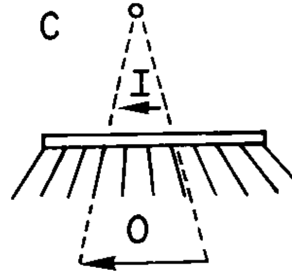
- Used with smaller diameter cameras (mobile cameras) to obtain large field of view (e.g. lung scanning)
- Cause image minification

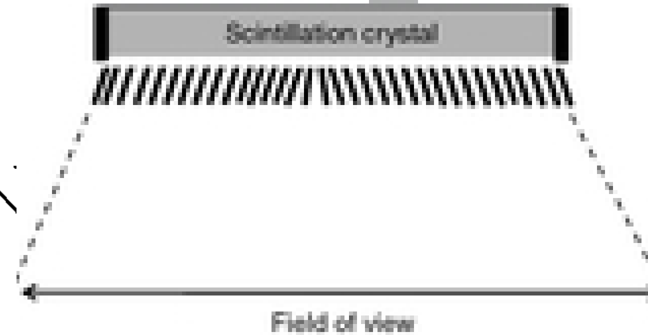
3- convergent hole collimator:

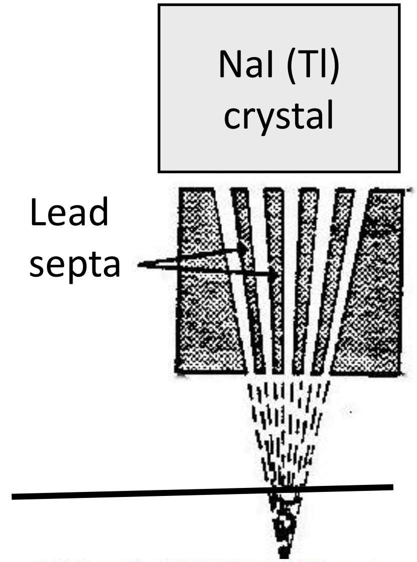
- Holes converge to a point inside the patient
- Magnifies the image
- Reduce the FOV
- Used for imaging of children or small organs
- Spatial resolution deteriorates towards the edge of the field

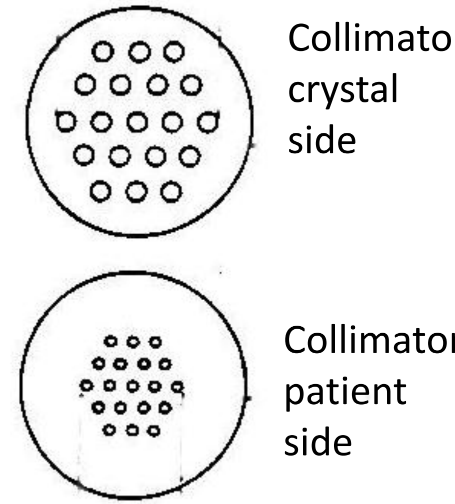
N.B: Types 2 & 3

- suffer from geometrical distortion (back of the organ is magnified or minified in relation to its front)
- FOV & in air sensitivity differs with distance

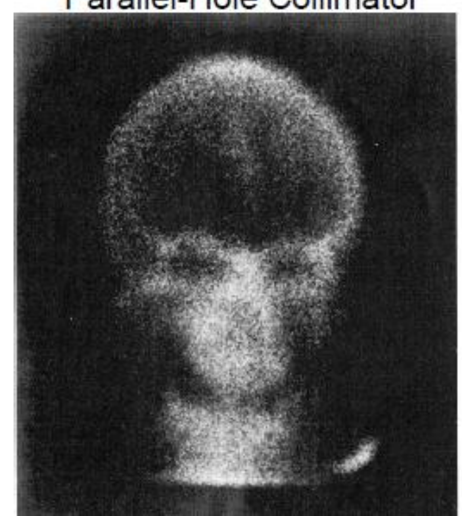




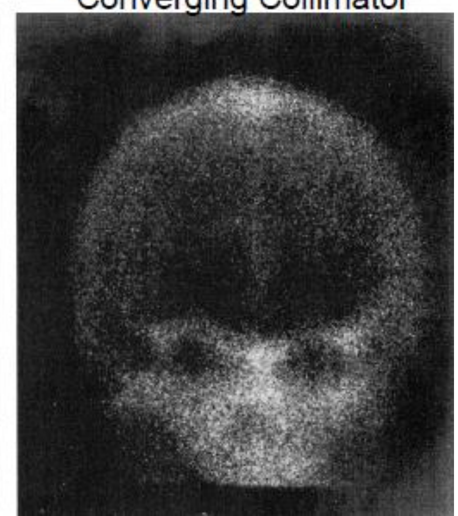




Parallel-Hole Collimator



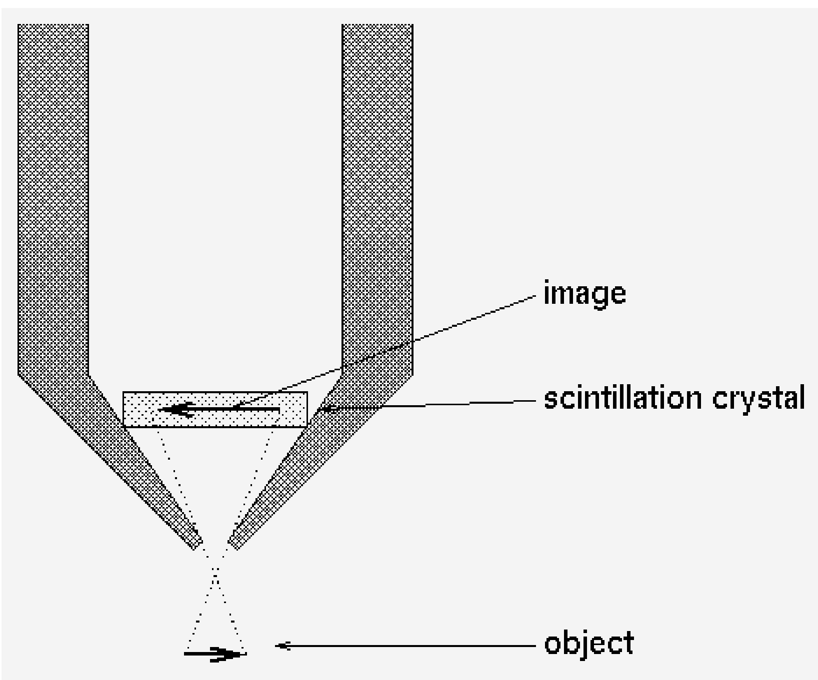
Converging Collimator

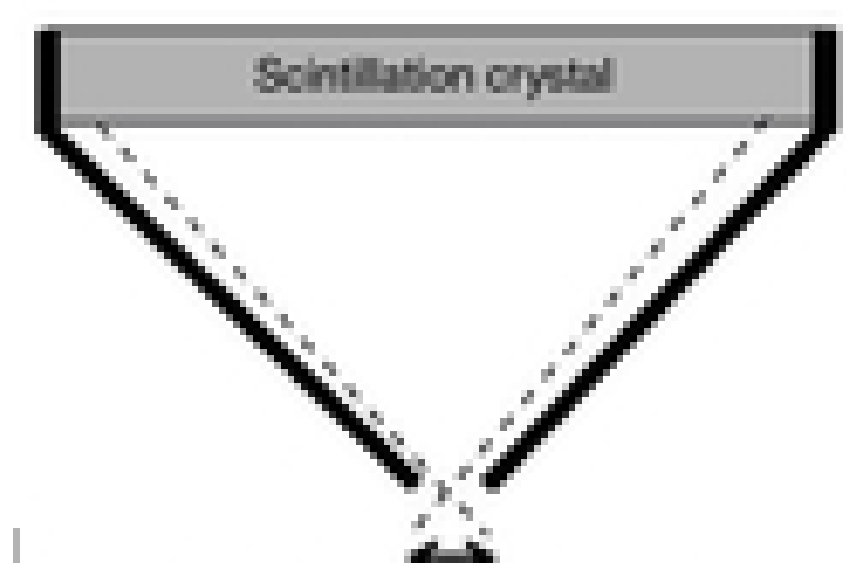


4- Pin hole collimator:

Cone of lead , with single hole (few mm in diameter) at its apex

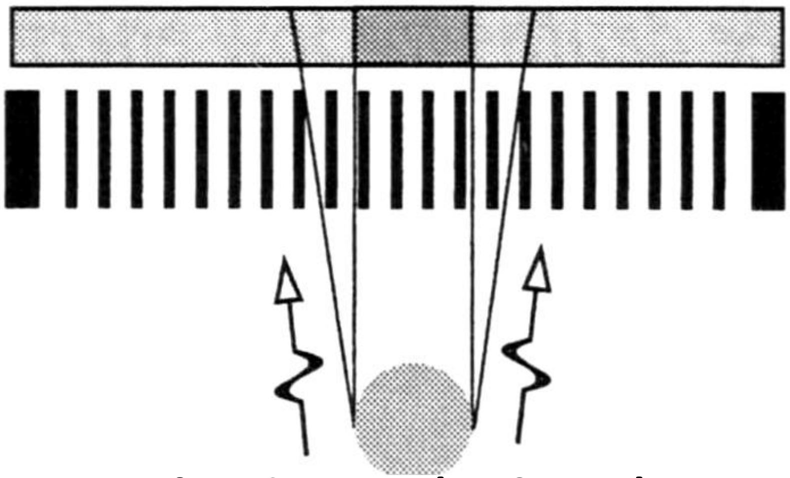
Produce magnified but inverted image of a superficial small organ e.g. thyroid





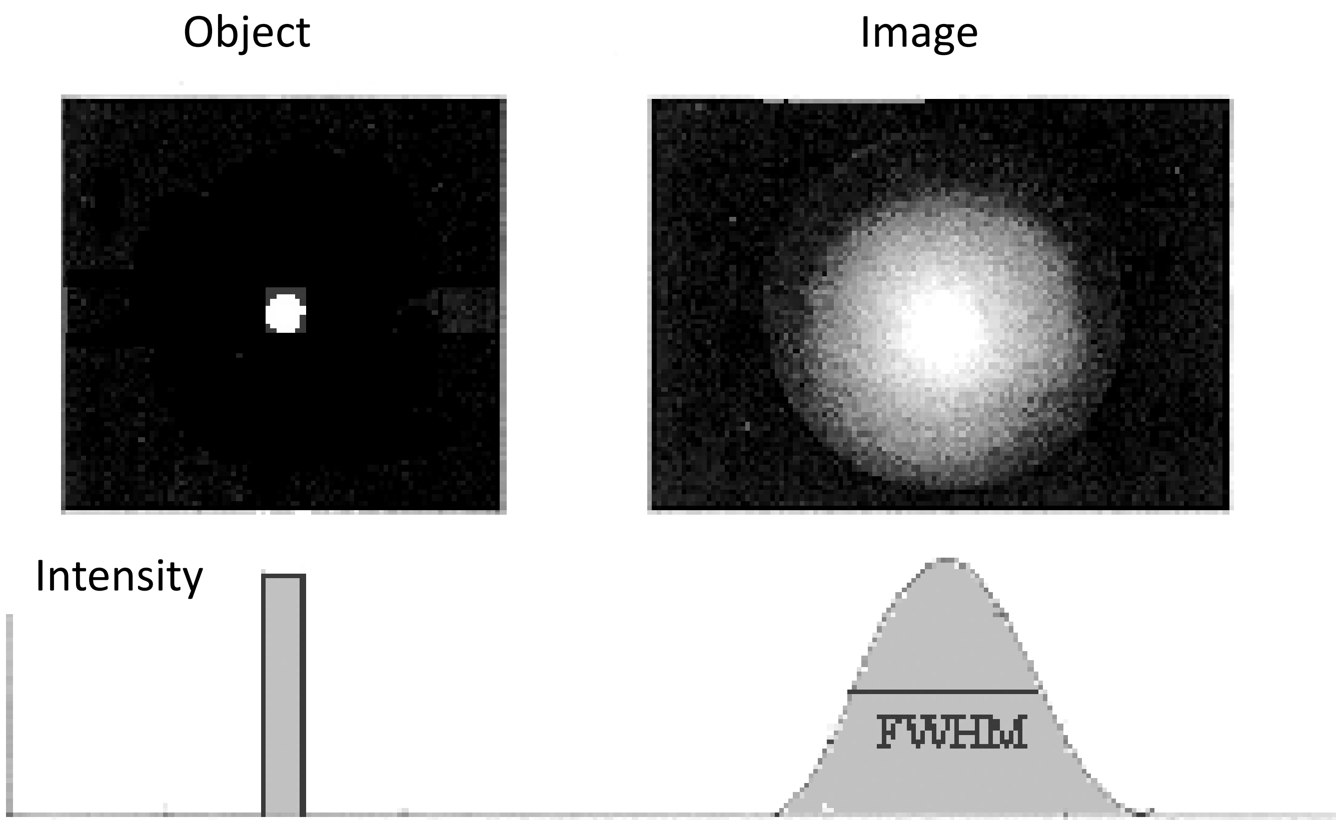
Collimator sensitivity

- Portion of gamma rays falling on the collimator from all directions that pass that pass from the holes
- About 1%
- Expressed as counts per second/MBq
- Sensitivity increase with :
  - ↑ number of holes
  - ↑ width of the holes
  - ↓length of the holes

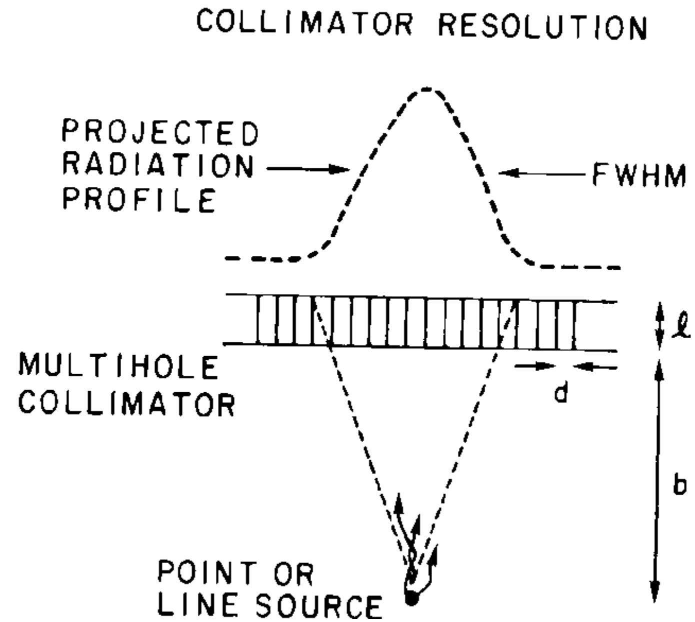


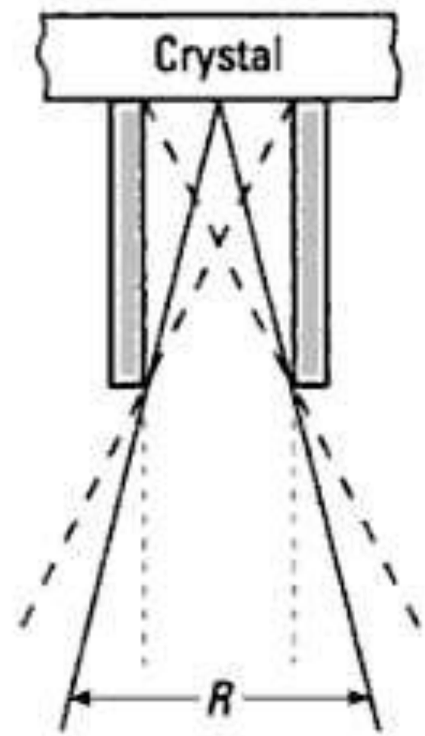
- ↑sensitivity → ↓ required patient's dose (why?)

Collimators and spatial resolution

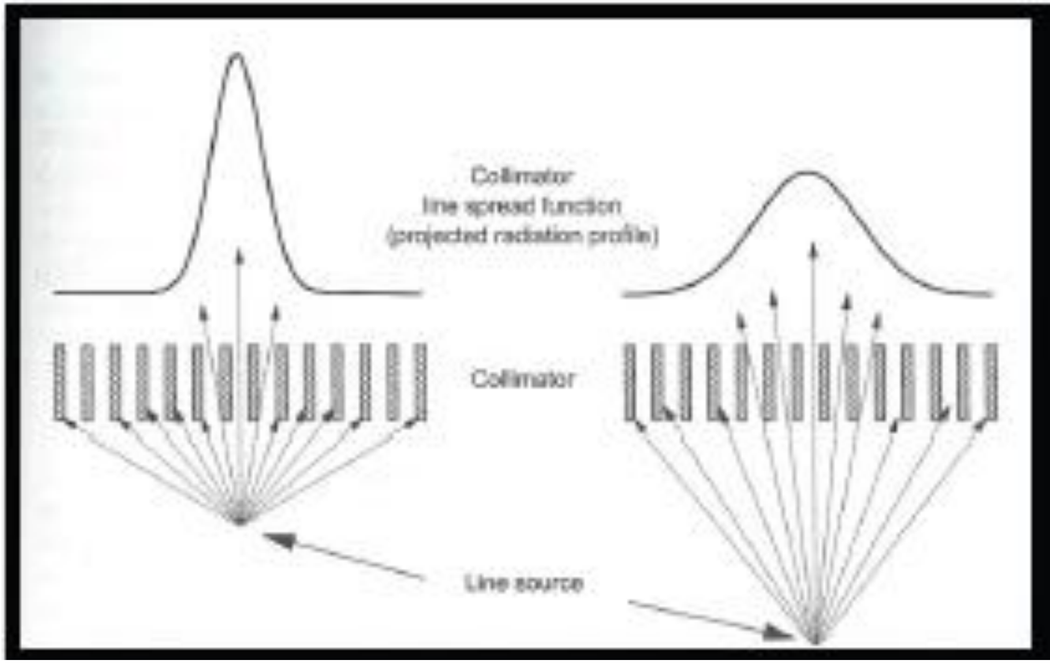


- R is a measure of Collimator resolution (=FWHM = full width at half maximum)
- The larger is R, the ………. Is the resolution

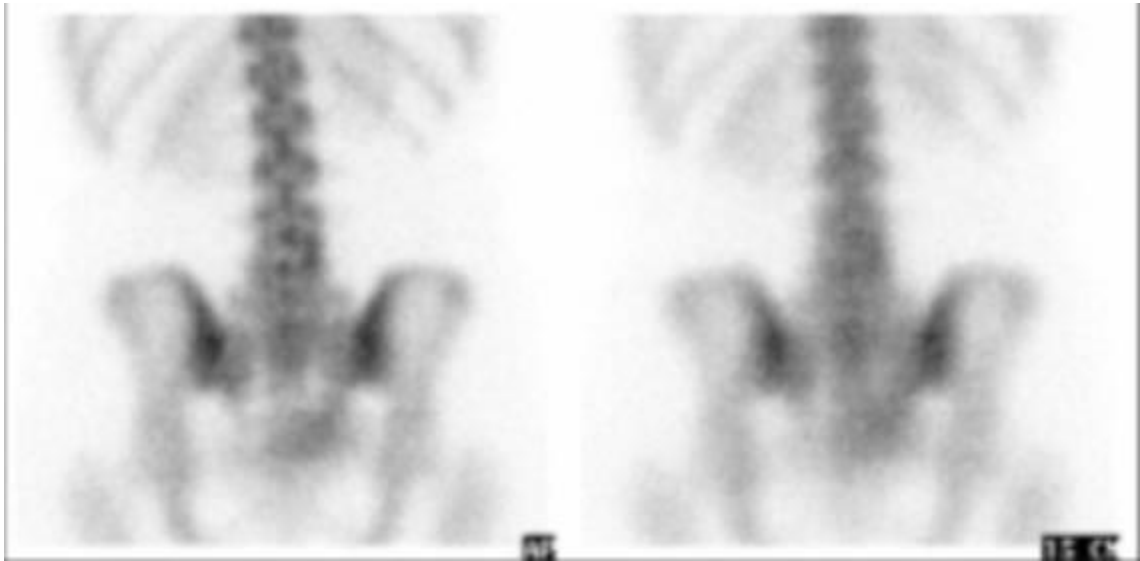




- Collimator resolution depends on:
  - I)Distance of the source from the face of collimator (resolution is best close to collimator)



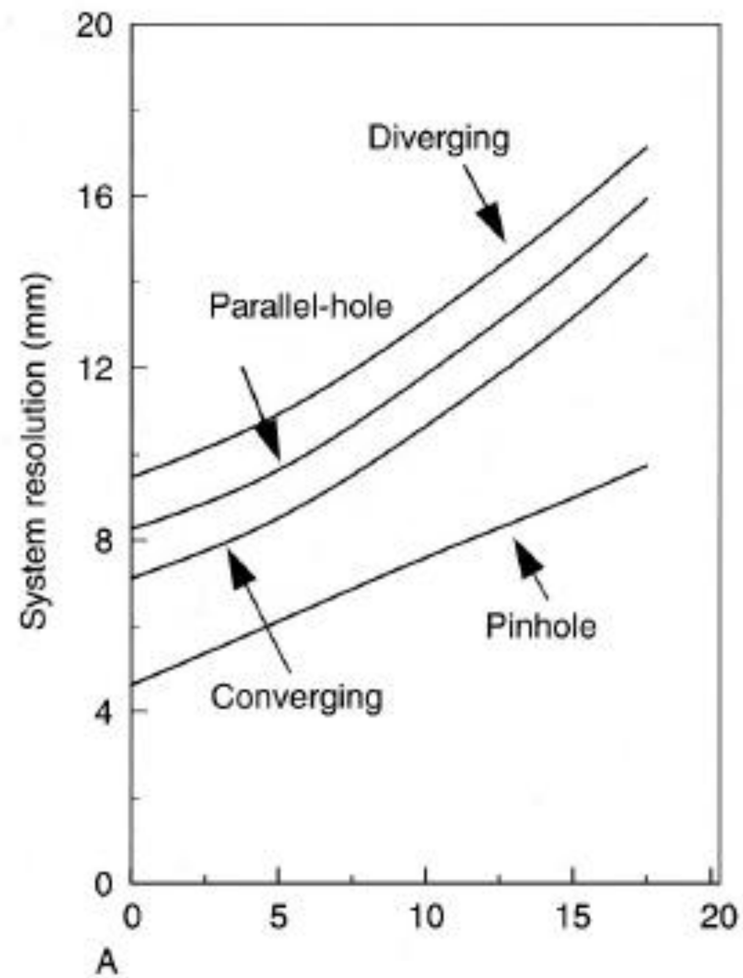
Optimal Large distance



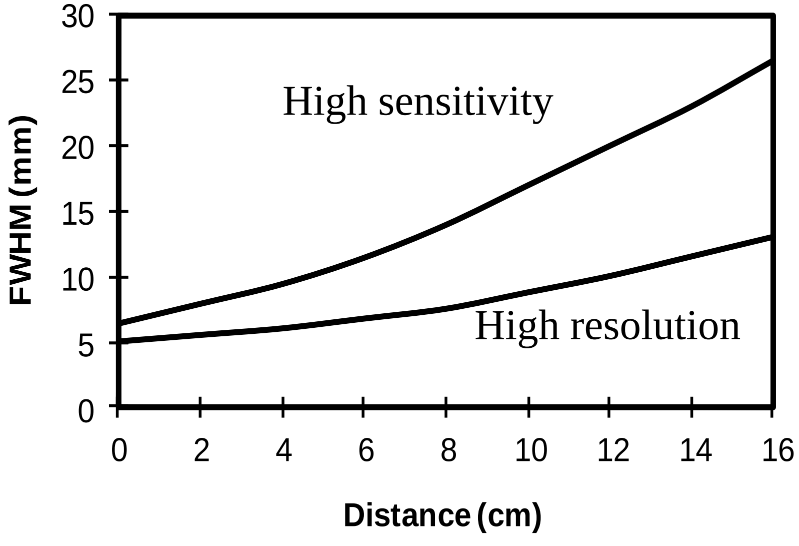
– II)Width of the holes (↑ Width→ ↓resolution)

– III)Length of the holes resolution (↑ length→ ↑ resolution)

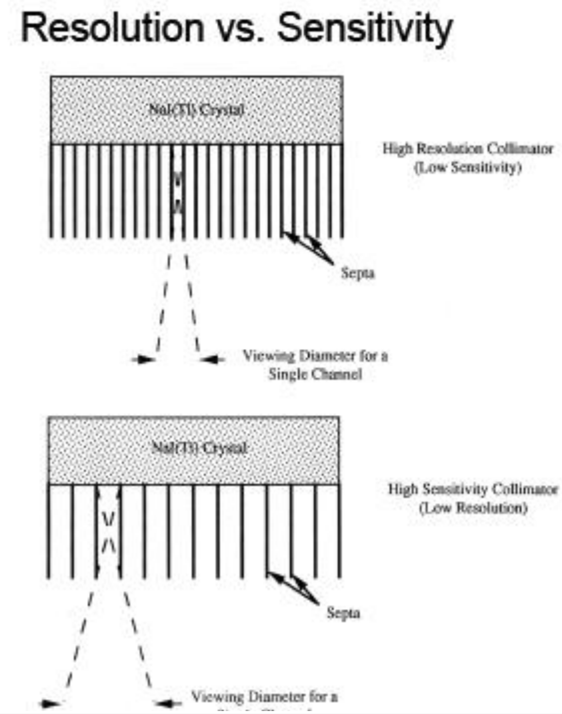
– IV) Type of collimator



- What is the relationship between collimator sensitivity and resolution?

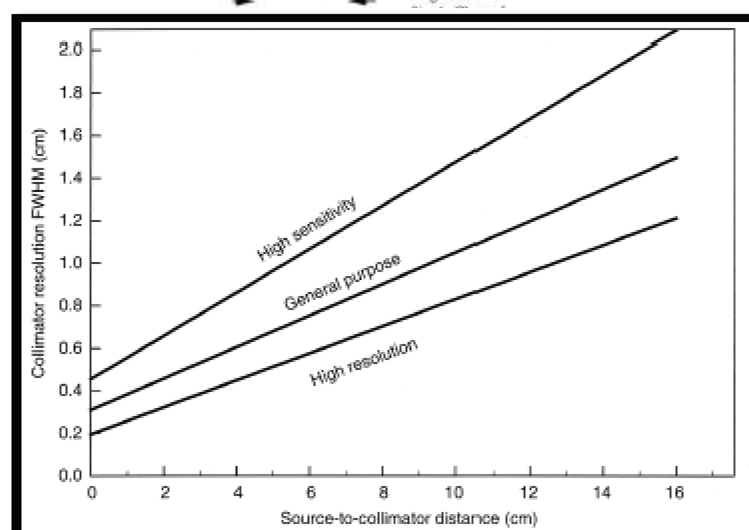


Types of collimators according to radionuclide energy



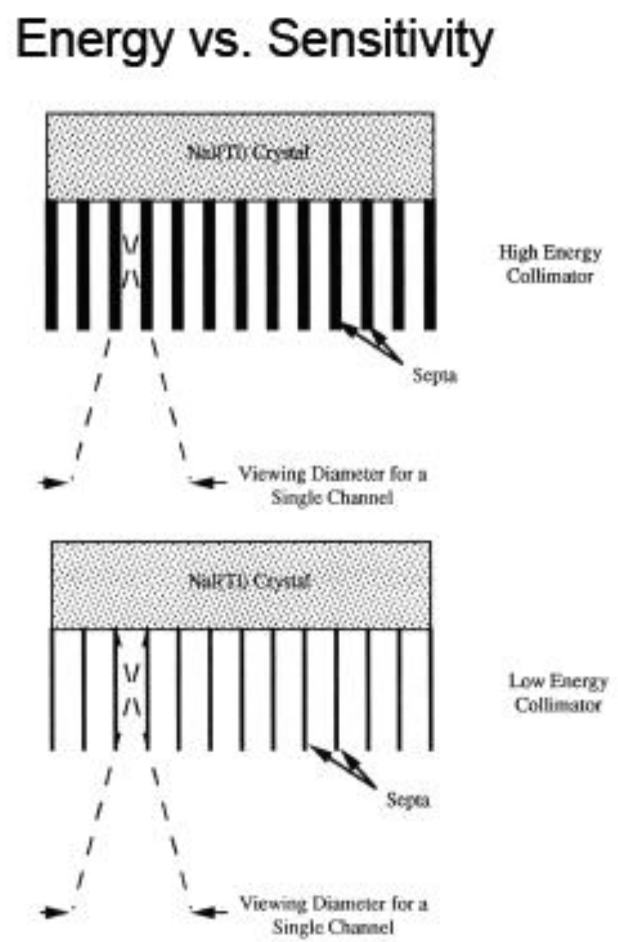
1) low energy collimators:

- Used for γrays of up to 150 kev (e.g. Tc)
- Have thin septae (0.3 mm)
- Types:
  - **General purpose collimator:**
    - Have 20000 holes , each is 2.5 mm in diameter
    - Resolution at 10 cm from the collimator face = 9 mm (=R)
    - Sensitivity = 150 cps/MBq
  - **High resolution collimator:**
    - More and smaller holes
    - Lower sensitivity
    - Used when high resolution is required , and when amount of radioactivity and imaging time can be increased
  - **High sensitivity collimator:**
    - Fewer and larger holes and poorer resolution
    - Used in dynamic imaging (short exposure times are necessary and poorer resolution is accepted)



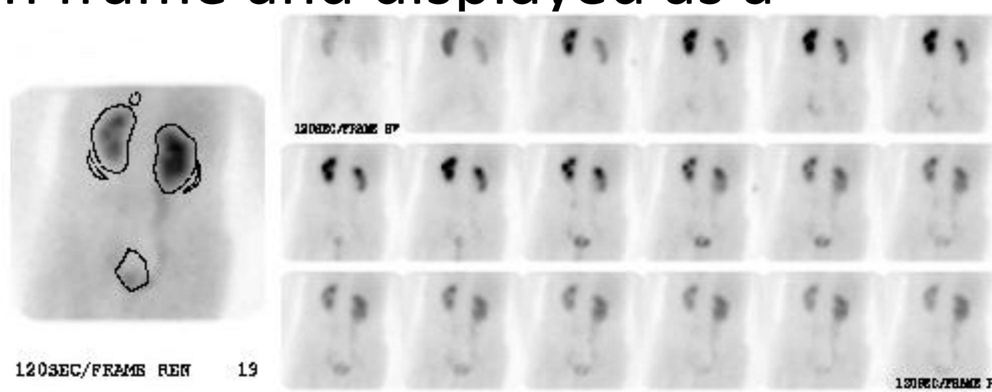
2)medium energy collimators:

- Up to 400 kev energy (In-111 , Ga-67, I-131)
- Have thicker septa (1.4 mm) → fewer holes and lower sensitivity



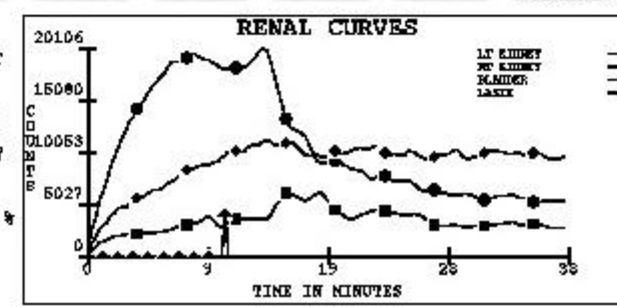
Dynamic imaging

- Definition: acquiring series of separate image frames in rapid succession
- Uses: study the function of organs (e.g. kidney , heart)
- Frames are either:
  - Recorded side by side on a single film
  - Repeatedly displayed seriatim on the screen as cine loop
- region of interest (ROI) is defined by a cursor and the total counts are measured on each frame and displayed as a function of time



RENOGRAM CURVE RESULTS

CURVES IN COUNTS	LEFT	RIGHT
PEAK TIME in MIN:	15.3	15.7
PEAK COUNTS:	20106	11144
T 1/2 in MIN:	4.3	208.7
DIFFERENTIAL (%):	70.9 %	29.1 %
DIFF TIME in MIN:	3 MIN	
LASIX TIME MIN:	12 MIN	

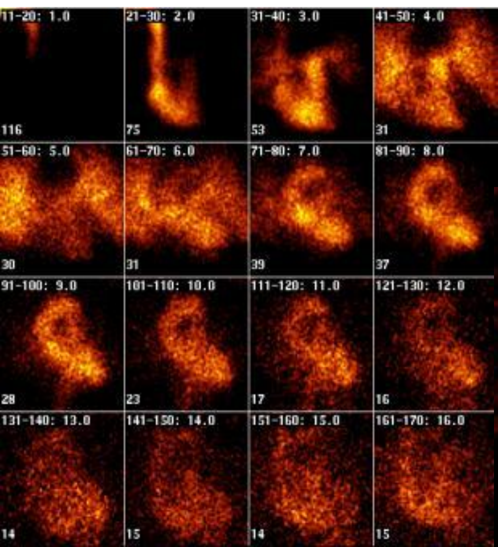


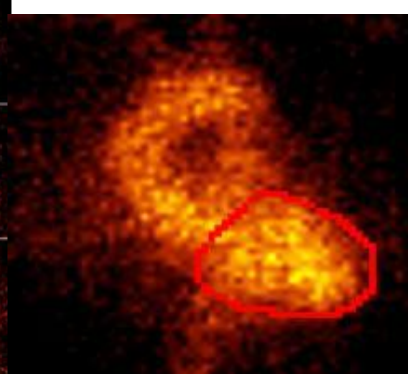
Iodine labeled hippuran study

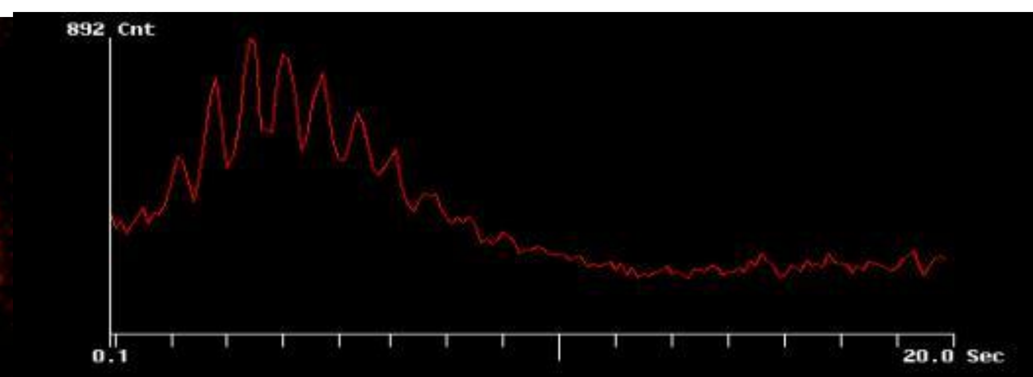
- Example of dynamic scanning:

<u>MUltiple GAted (MUGA) cardiac study:</u>

- Images acquired in 20-30 different points of the cardiac cycle (ECG gated)
- At each of these points : hundreds of successive images are added pixel by pixel (to ↓ noise)
- Quantitative data (ejection fraction) can be extracted



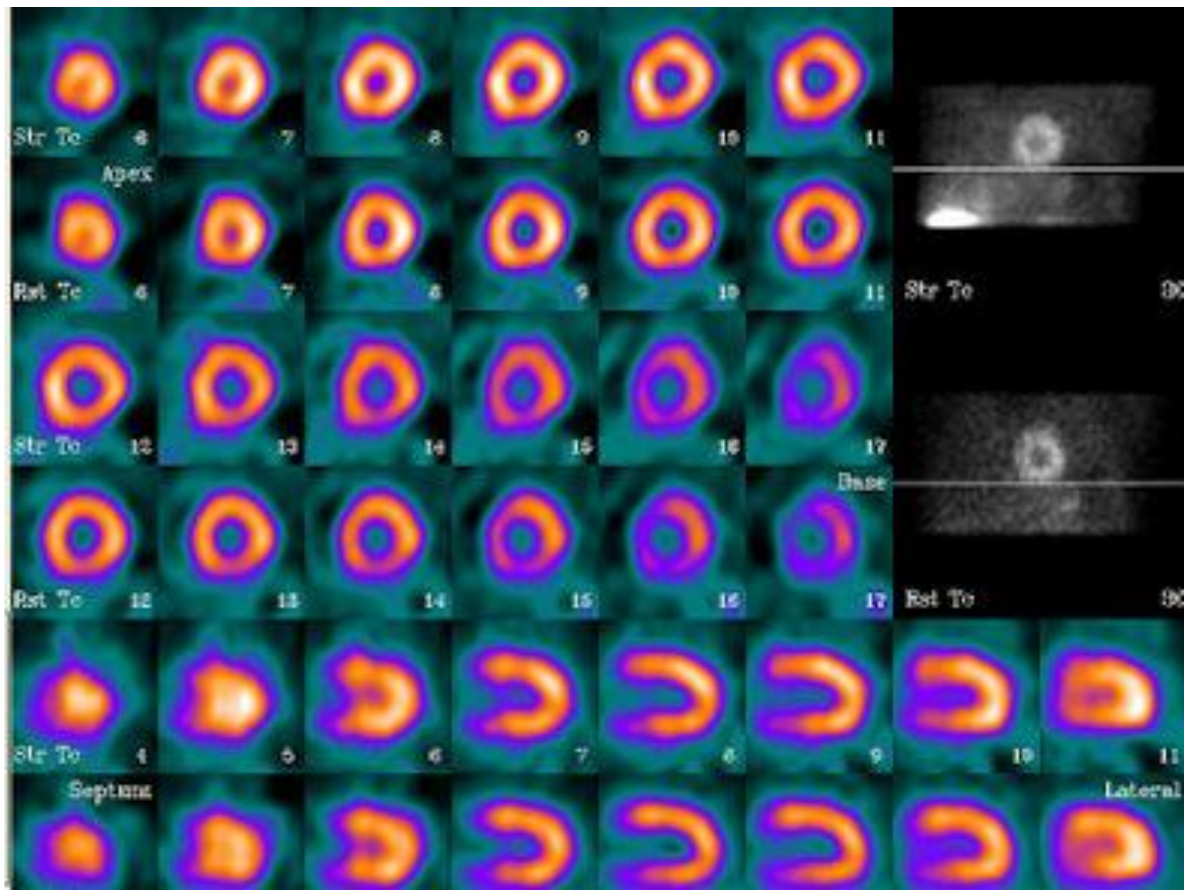




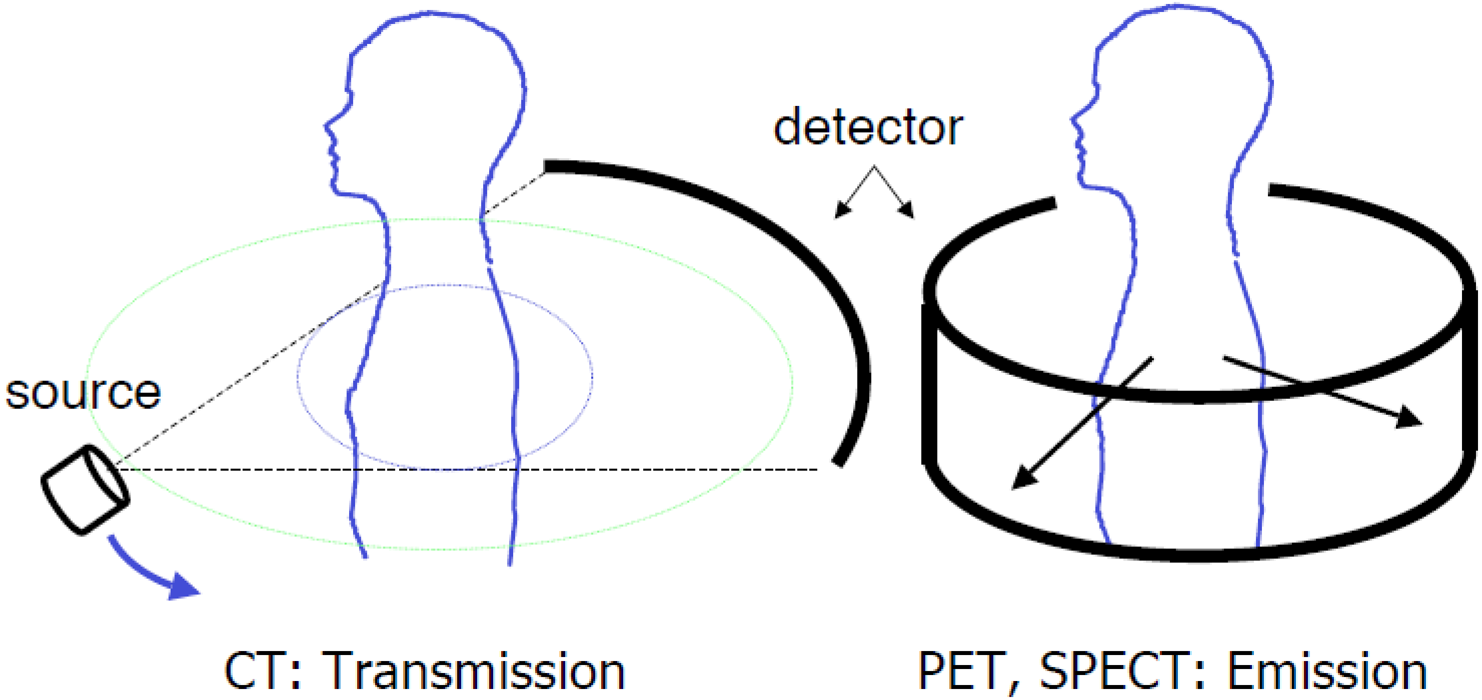
Single photon emission computed tomography

(SPECT)

- Planar images: produce 2D projection of the 3D tracer distribution (superimposition with contrast loss)
- SPECT= Sectional images (no superimposition)
  - **better contrast**
  - **more accurate lesion localization**



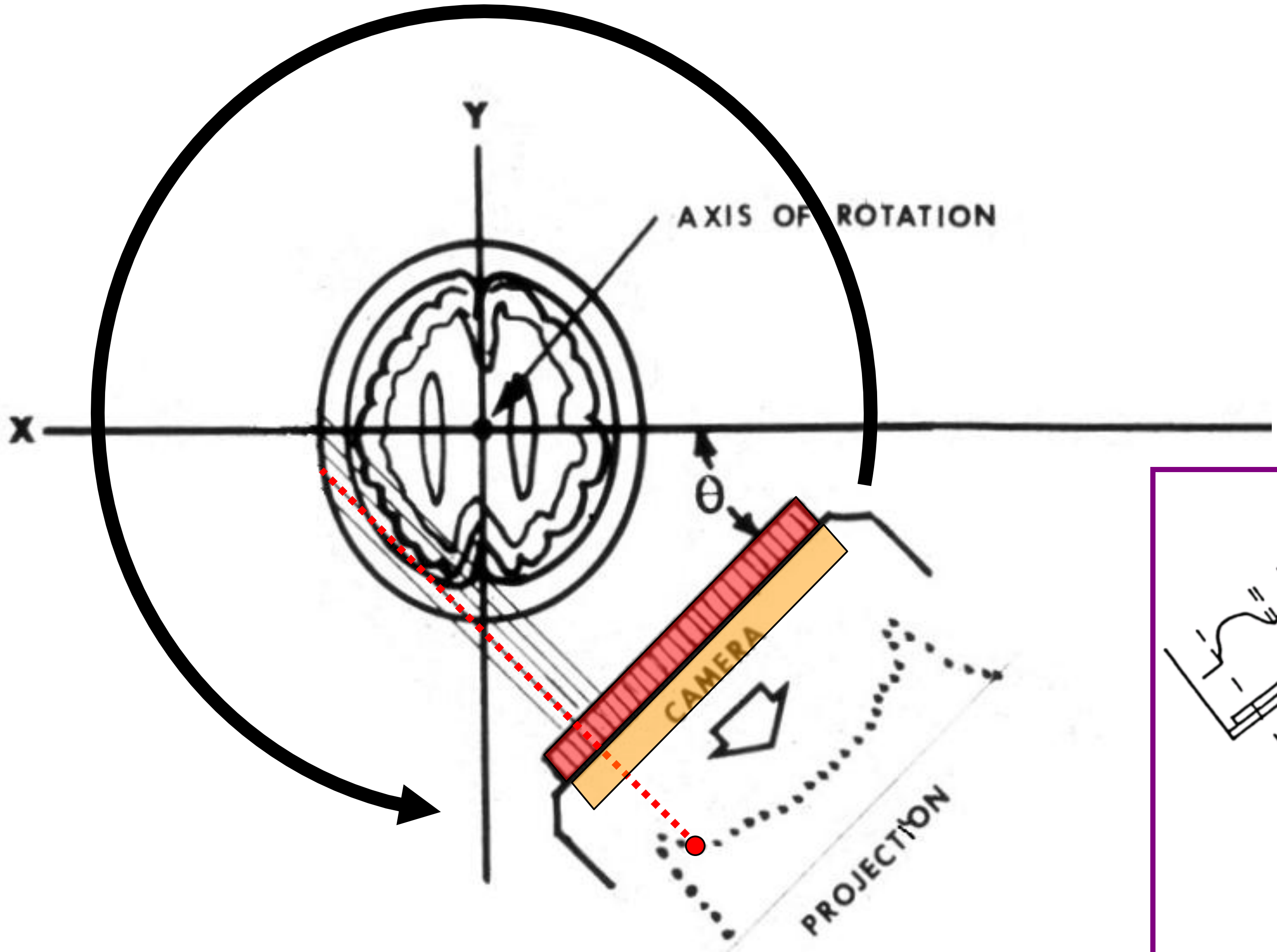
Emission and transmission tomography

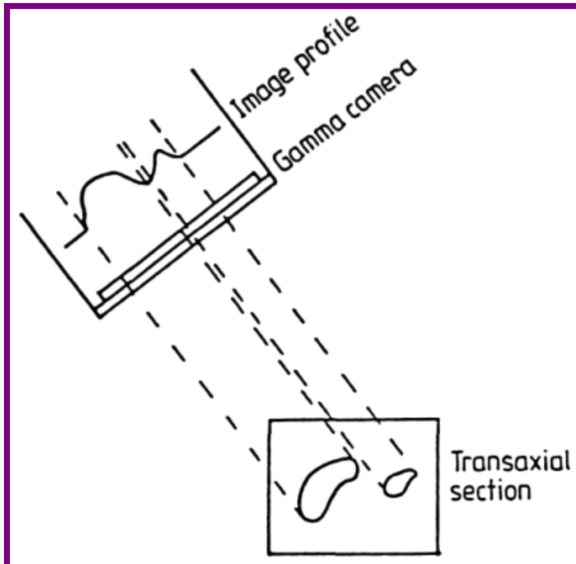


- Idea:

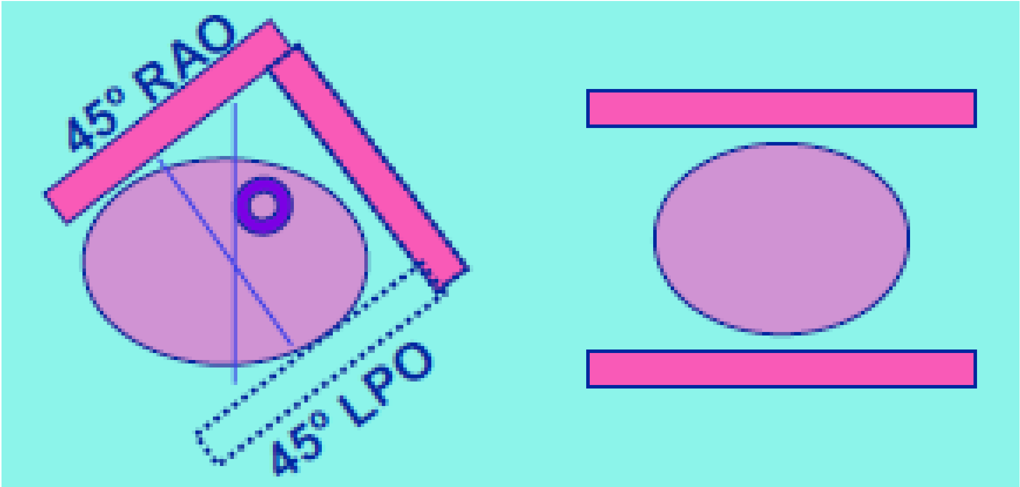
1- rotating Gamma camera with parallel hole collimator rotates around the patient

2- Every 6^{o} →camera acquires a view for 20-30 sec. (60 views taken in 30 minutes)



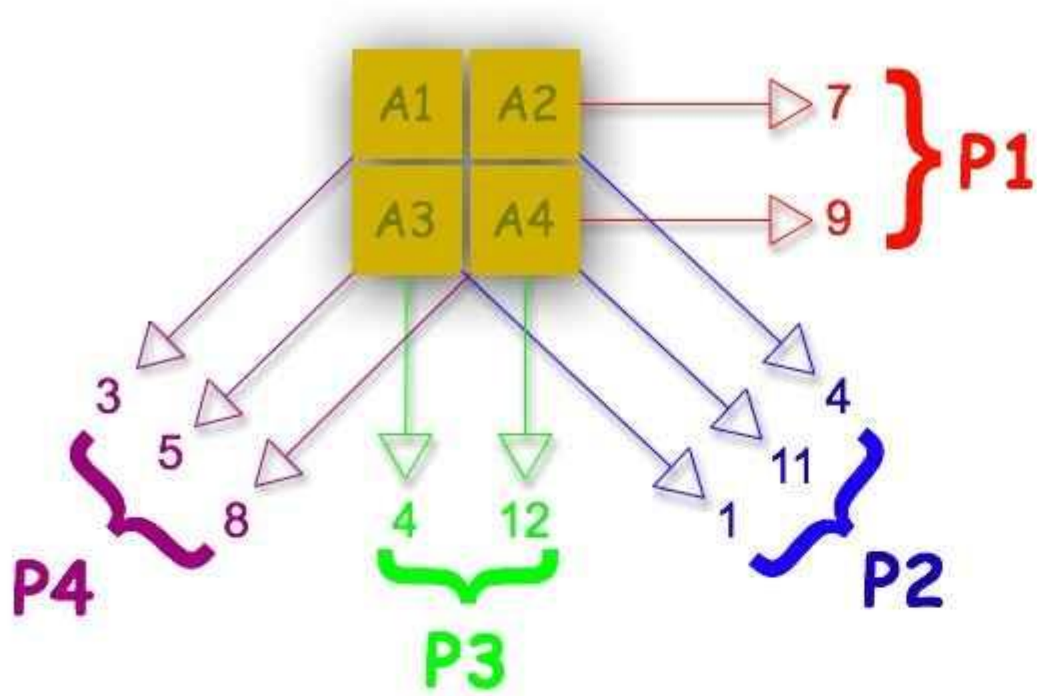


- Two camera heads can be used:
  - **2 perpendicular detectors with 180º rotation range or**
  - **2 opposite detectors with 360º rotation range**



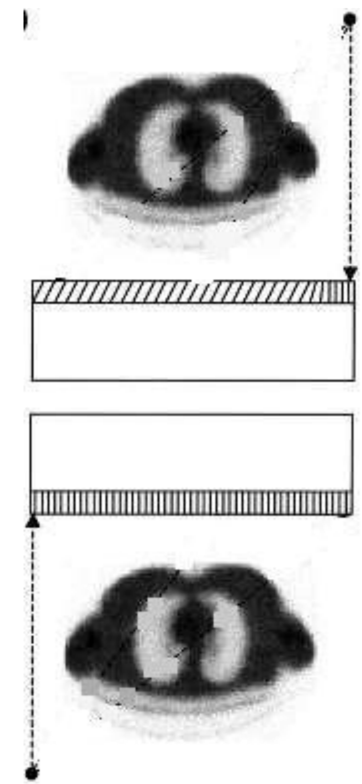
Result:

Each pixel line corresponds to a line of sight along which counts are summed (like the CT pencil beam)



algorithm for γ attenuation through the tissues

- Counts in the center of the patient are less than the periphery (due to photon attenuation by the patient)
- Solution: add counts pixel by pixel in each pair of opposing views $\rightarrow$ the combined counts are more nearly the same

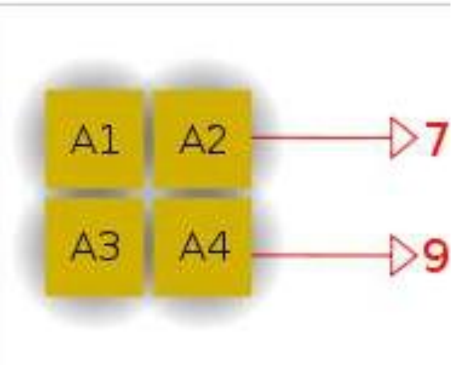


SPECT Image reconstruction

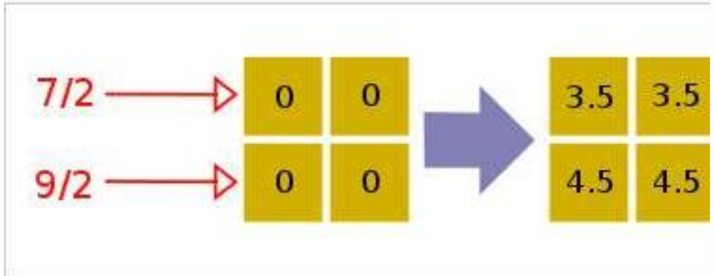
- **1) filtered backprojection:**

Method: see CT

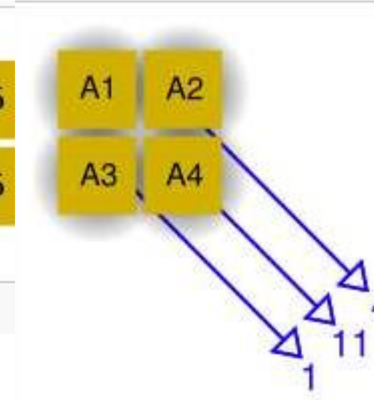
Disadvantage: Streaking of the areas of very high activity



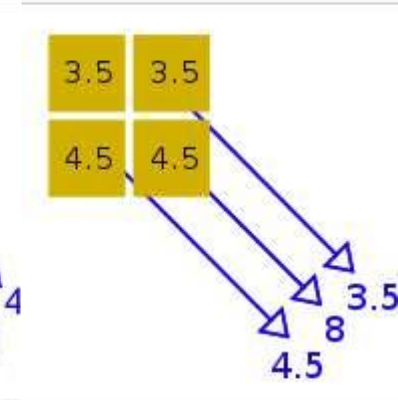
Actual projection, P1.



First estimate of image matrix.



Actual projection, P2.

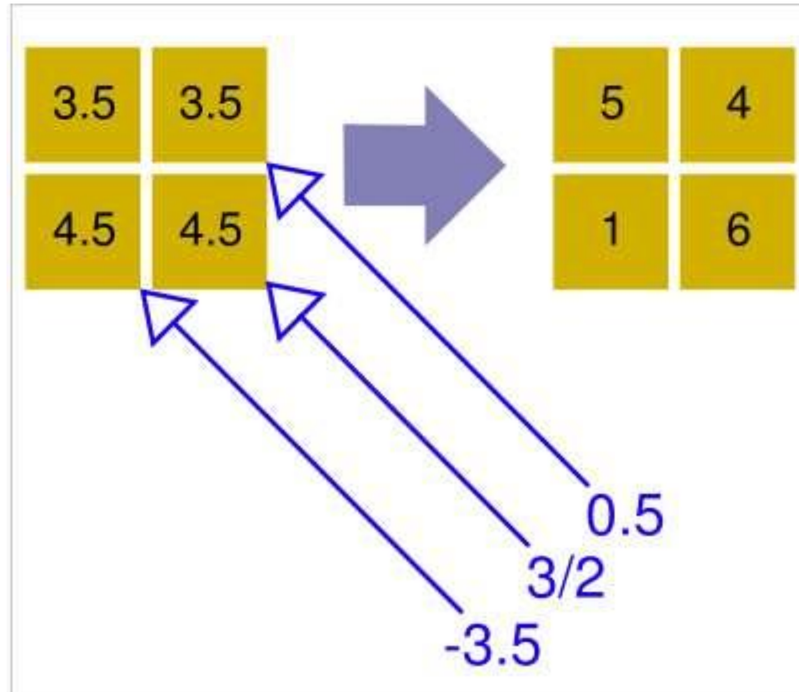


Estimate of projection, P2.

2) iterative reconstruction:

- steps:
  - Distribute the first projection evenly through the empty pixels → first estimate of image matrix
  - Compare: second actual projection with the same projection calculated from the estimated matrix in step 1
  - The difference between actual and estimated projections is added to the estimated matrix in step 1
  - Process is repeated for all other projections

i.e. image is adjusted in steps until it is as close as possible to the actual counts

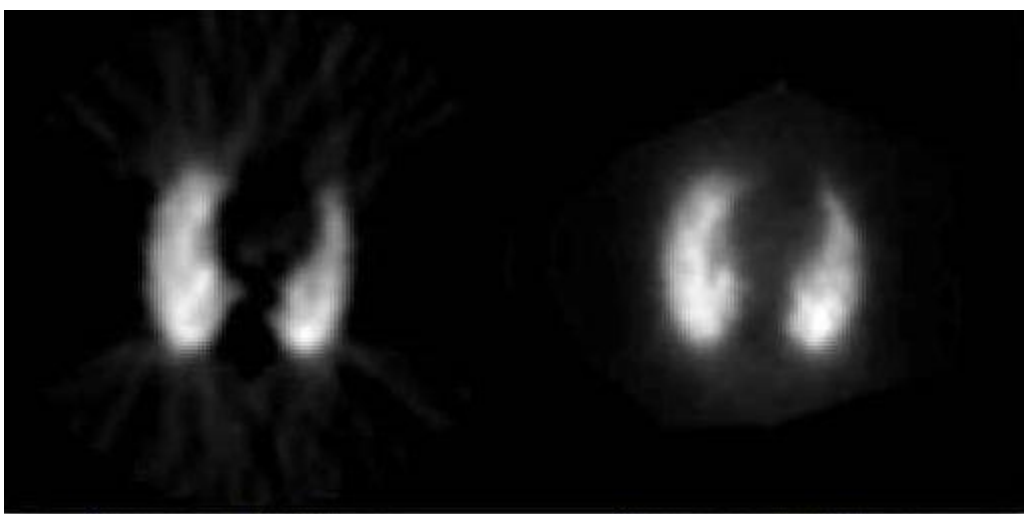


Second estimate of image matrix.

- Advantages of iterative reconstruction:
  1- less prone to artifacts of filtered backprojection

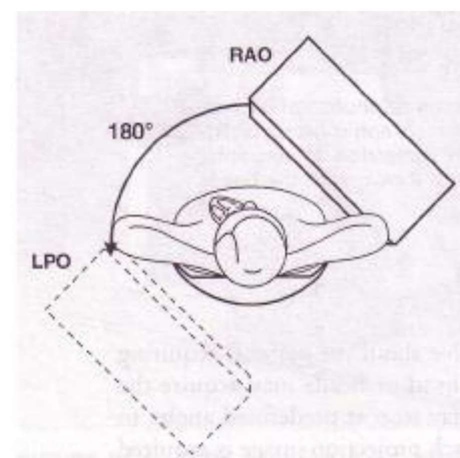
  2-insensitive to noise

  3-ability to reconstruct the image even when data acquisition is incomplete (e.g. 180º rotation only)



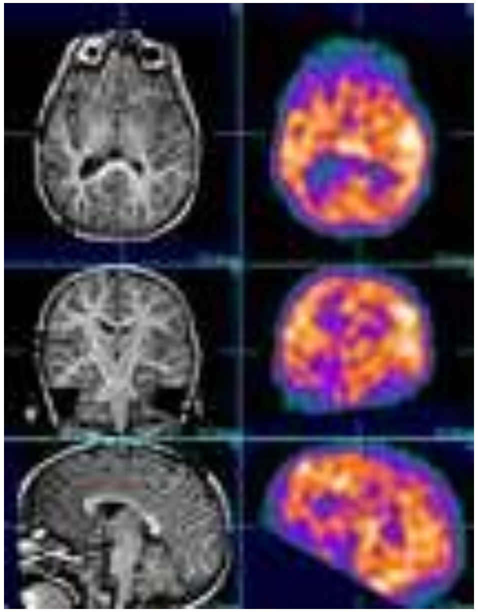
Slice reconstructed using Filtered Back Projection

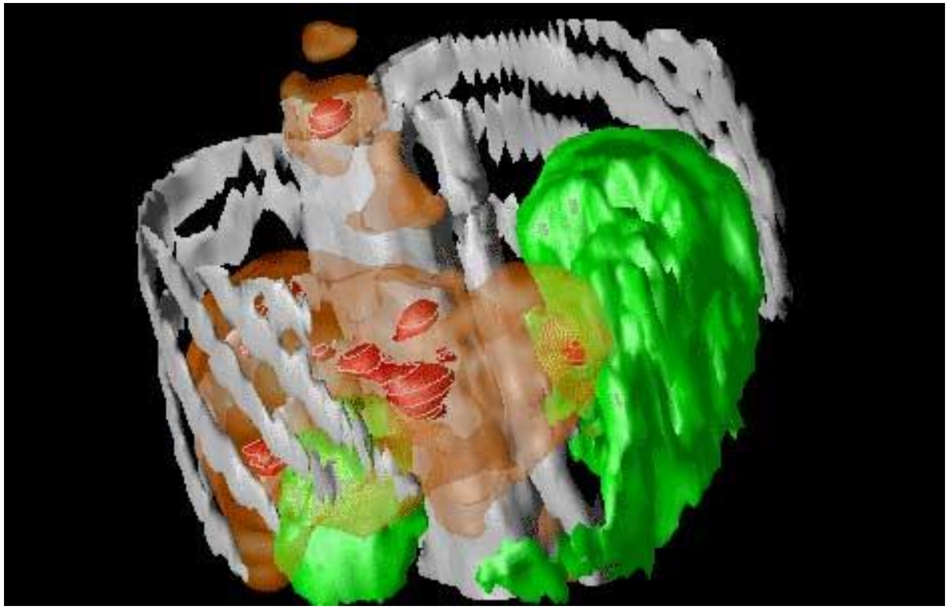
Slice reconstructed using Iterative Reconstruction



Results of reconstruction:

- 20-30 parallel transverse sections
- Sagital , oblique and coronal cuts can be reconstructed
- Continuously rotating 3D representation can be displayed (decrease effect of image noise)





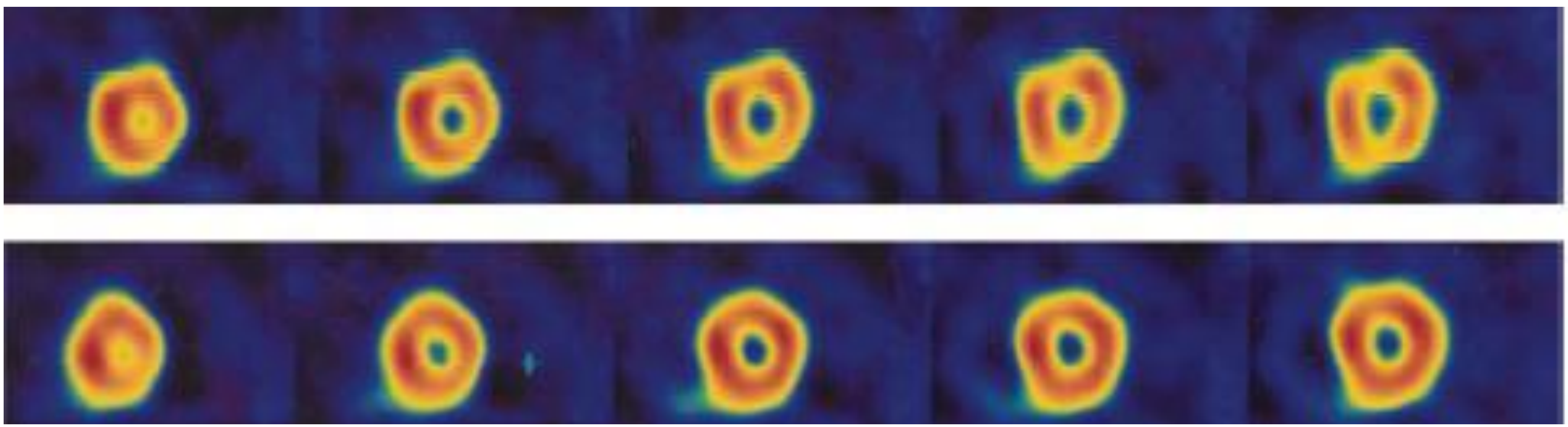
Disadvantages of SPECT

1-High amount of noise :

- *Cause:* 20-30 seconds only to collect data → limited number of counts for each voxel (i.e. photon limited)
- *Solutions:*
  - Reconstruct thicker slices (but this will increase volume average artifact)
  - Decrease matrix to 64 x 64
  - Iterative reconstruction
  - Low pass filtering (but deteriorate resolution)
  - Shielding PMTs from earth magnetic field (changing orientation)

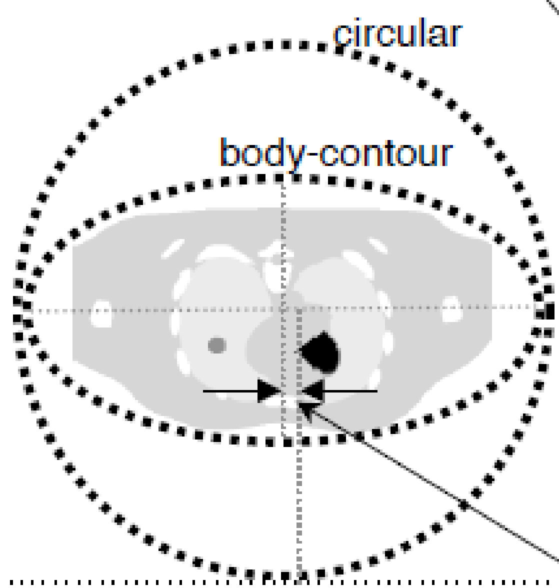
2-long overall imaging time:

- *Result:* motion artifacts
- *Solution:* movement compensation techniques



3- low spatial resolution

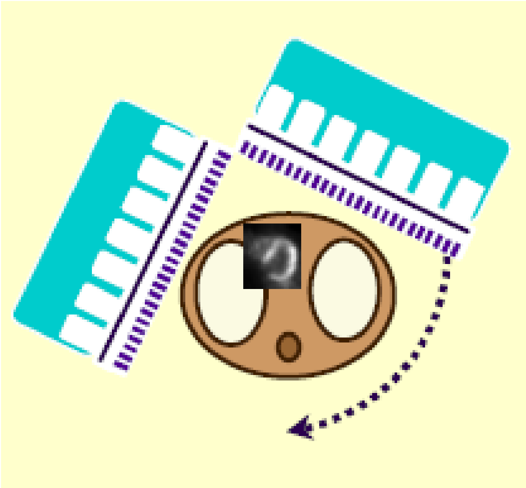
- Resolution is only 18 mm = 3 x pixel size (worse than conventional gamma imaging)
- *Causes:*
  - Each slice is reconstructed only from 64 measurements (64 x 64 matrix) in 30 angular positions
  - Use of high sensitivity collimator (why?)
  - Patient's motion
- *Solution:*
  - Elliptical orbit of camera to decrease the gap between collimator and patient
  - Use of 3 or 4 equally spaced gamma cameras → decrease time and higher resolution
  - Increase number of measurements (120 images at 3 degree steps instead of 60 images at 6 degree steps)



Applications of SPECT

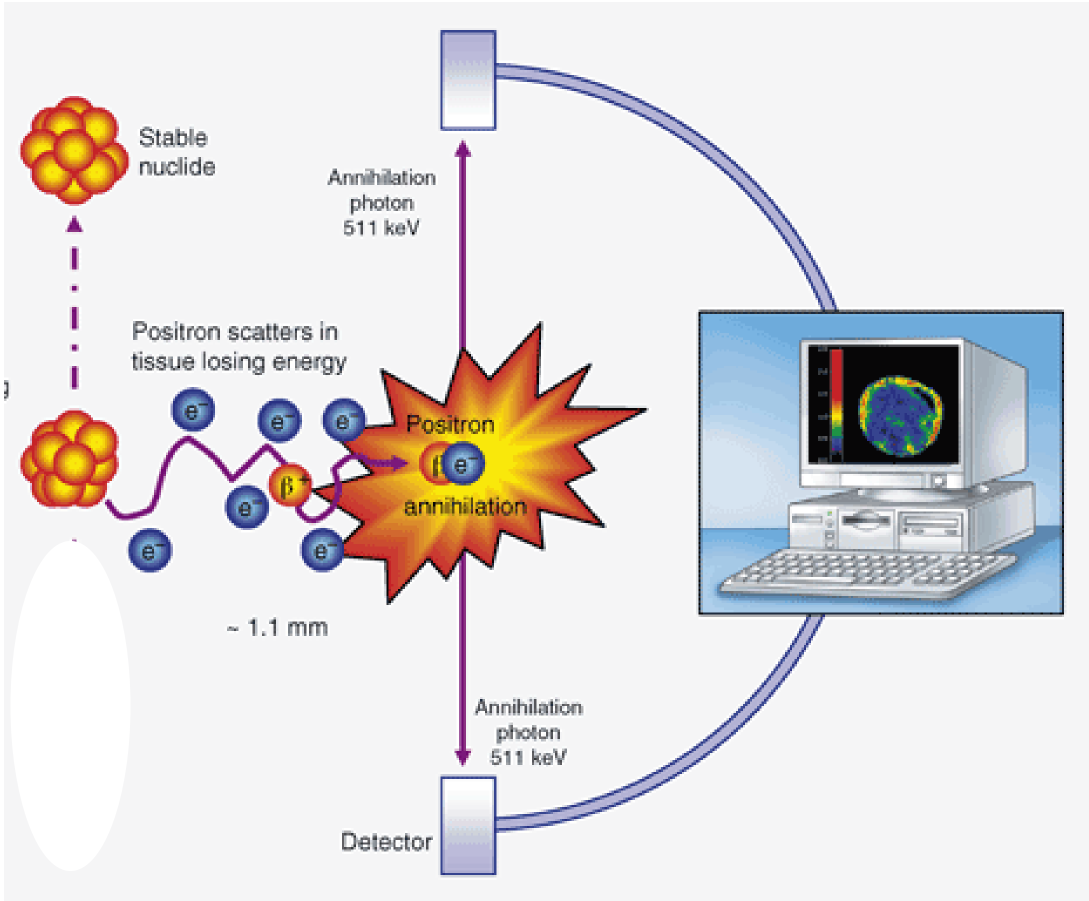
- Study of myocardial infarction
- Quantitative analysis of cerebral blood flow
- Tumour detection

N.B: for cardiac SPECT: 180 Degree Acquisition is enough (Heart not visible in posterior projections)



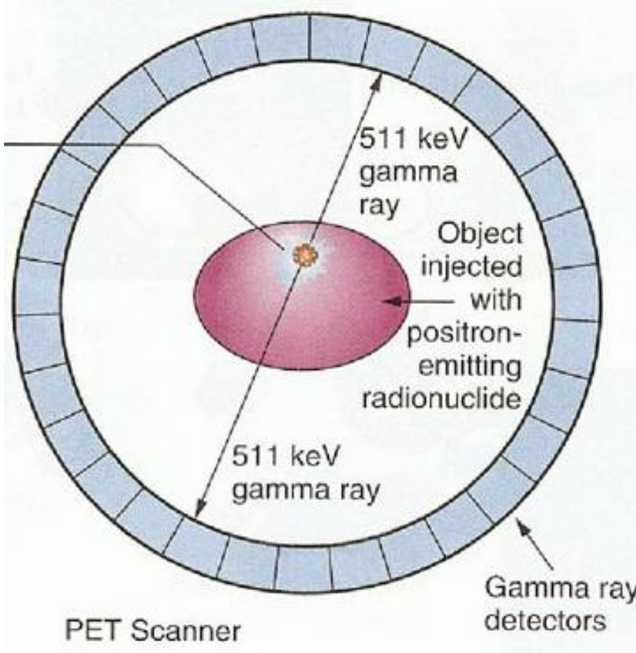
Positron emission tomography
PET

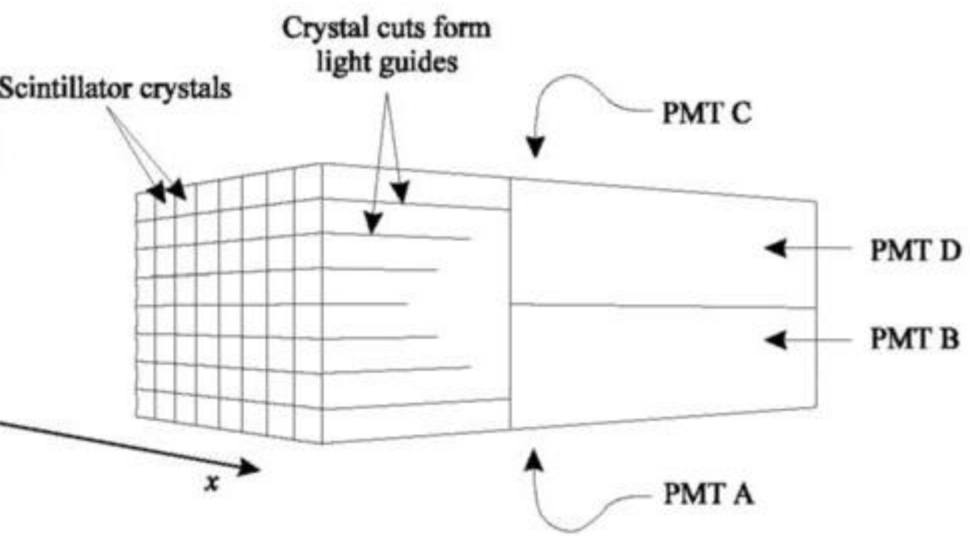
- Most common positron emitter used: F-18 + deoxyglucose (FDG) → annihilation (see before)
- Idea of PET: detection of the two annihilation photons in coincidence and identify their origin in the patient

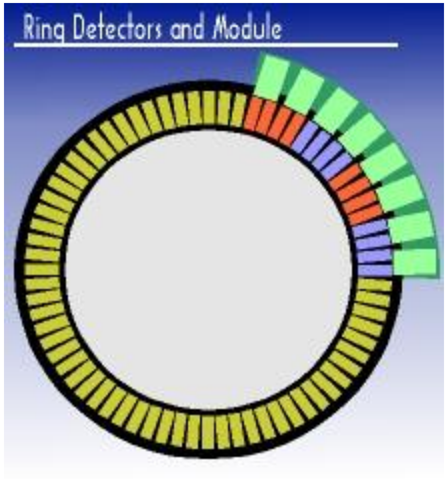


PET camera:

- *Composition*: Ring of very large number of detectors (10000-20000) surrounding the patient (axial FOV = width of detectors ring)
- Ideal detectors must be:
  - Readily available and cheap
  - Easy to manufacture as crystal blocks
  - High detection efficiency for 511 kev photons
  - Very short scintillation decay time
  - Good energy resolution
- Detectors used:
  - solid scintillation detector using a Scintillator:
    - bismuth germinate (BGO)
    - lutetium oxyorthosilicate (LSO)
    - Gadolinium oxyorthosilicate (GSO)
  - Commonly made in a block format , coupled with the PMTs







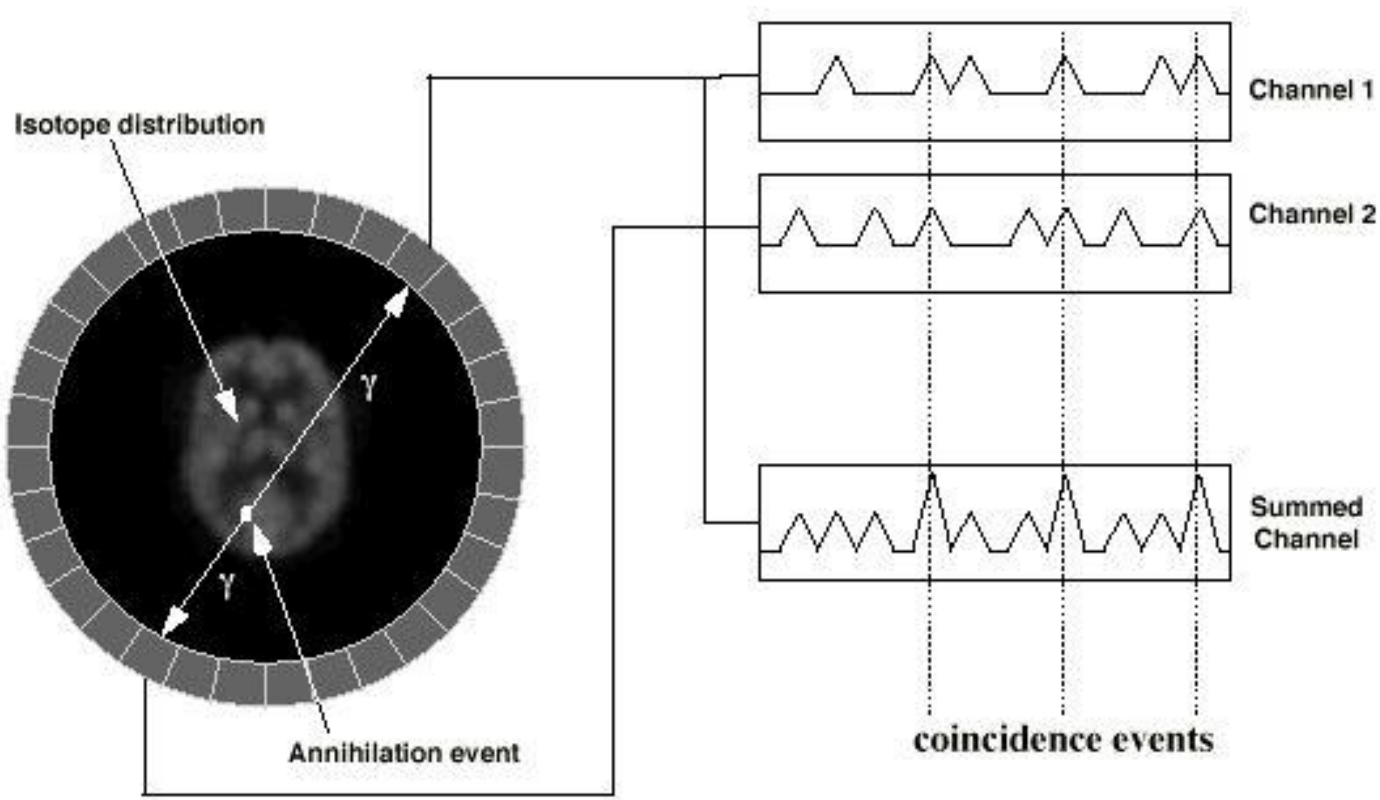
Comparison between Scintillator detectors used in PET (compared to NAI)

Property	comparison
Z & E resolution	BGO & LSO >GSO>NaI
Decay time	LSO & GSO < NaI<BGO
Light output (Conversion efficiency)	NaI > LSO > GSO > BGO

N.B. Compromise is necessary when choosing the type of detector used

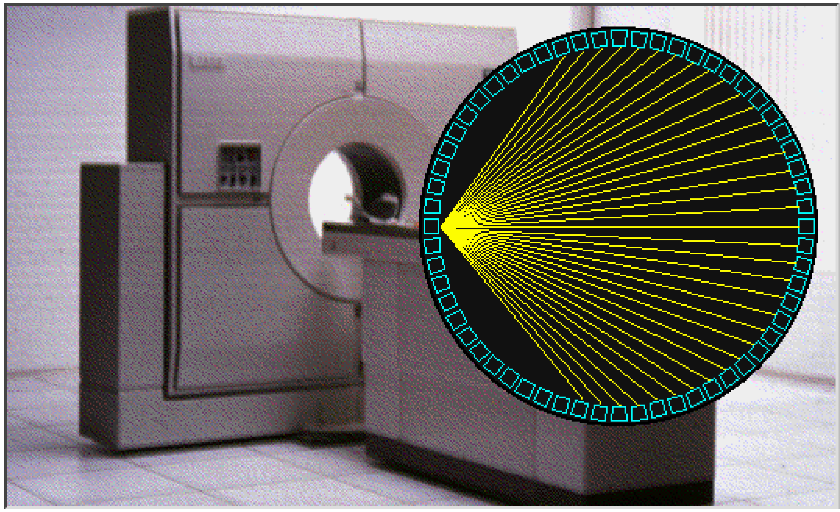
Coincidence events

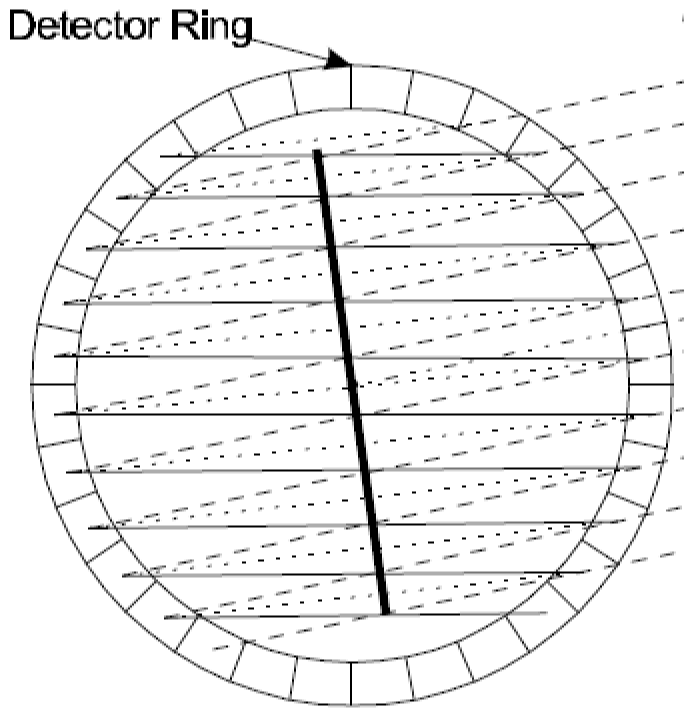
- Annihilation event occur → annihilation photons enter two opposite detectors producing simultaneous (coincident) pulses
- Any coincident pulses in in two opposite detectors → accepted and combined by electronics
- Any non Coincident pulses (e.g. background radiation) → ignored



Lines of response (LOR)

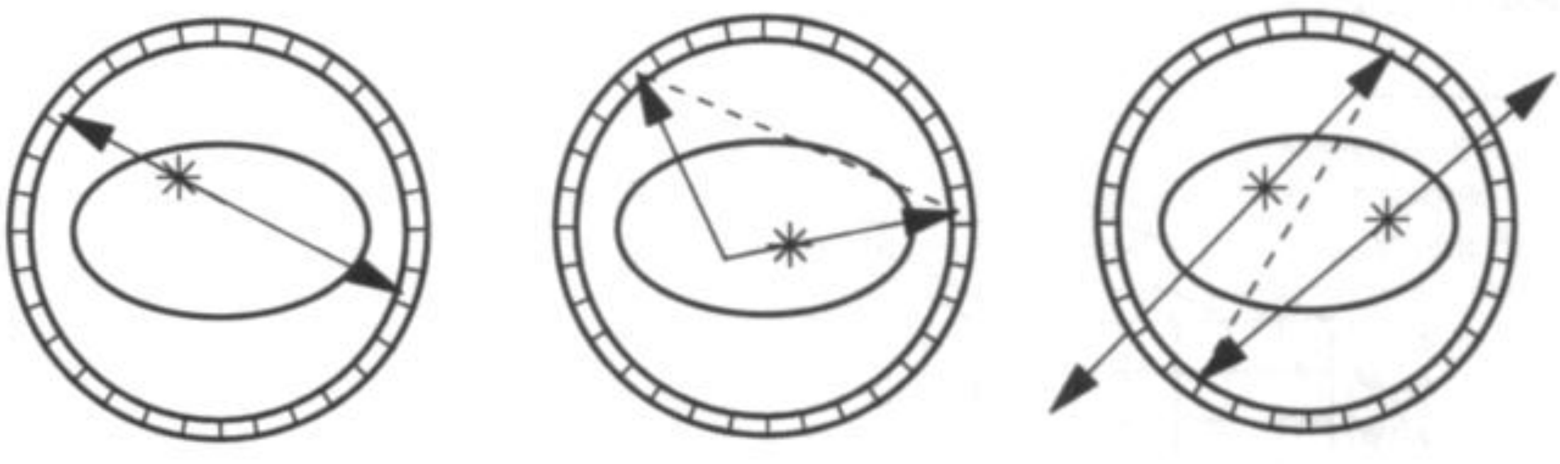
- Each detector can operate in coincidence with about half of detectors that face it in the detector ring (line between them = line of response)
- This allows a computer to distinguish between random and true coincidences to locate the origin.
- So that patient is criss crossed by hundreds of LORs





Types of coincidence events

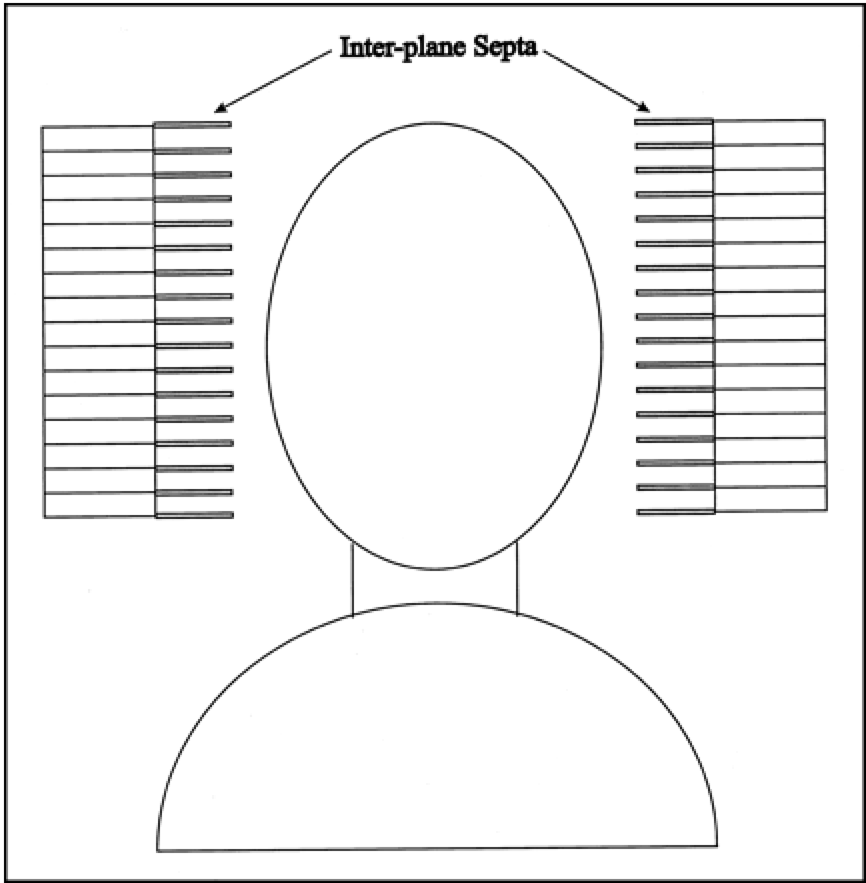
- A *true coincidence* is the simultaneous interaction of emissions resulting from a single nuclear transformation
- A *scatter coincidence* occurs when one or both of the photons from a single annihilation are scattered, but both are detected
- A *random coincidence*, occurs when emissions from different nuclear transformations interact simultaneously with the detectors



How to reduce random and scatter events

- Narrow lead or tungsten septa (1 mm thick , 10 mm deep) are used between each ring of detectors (in Z plane)

i.e. act as antiscatter grid



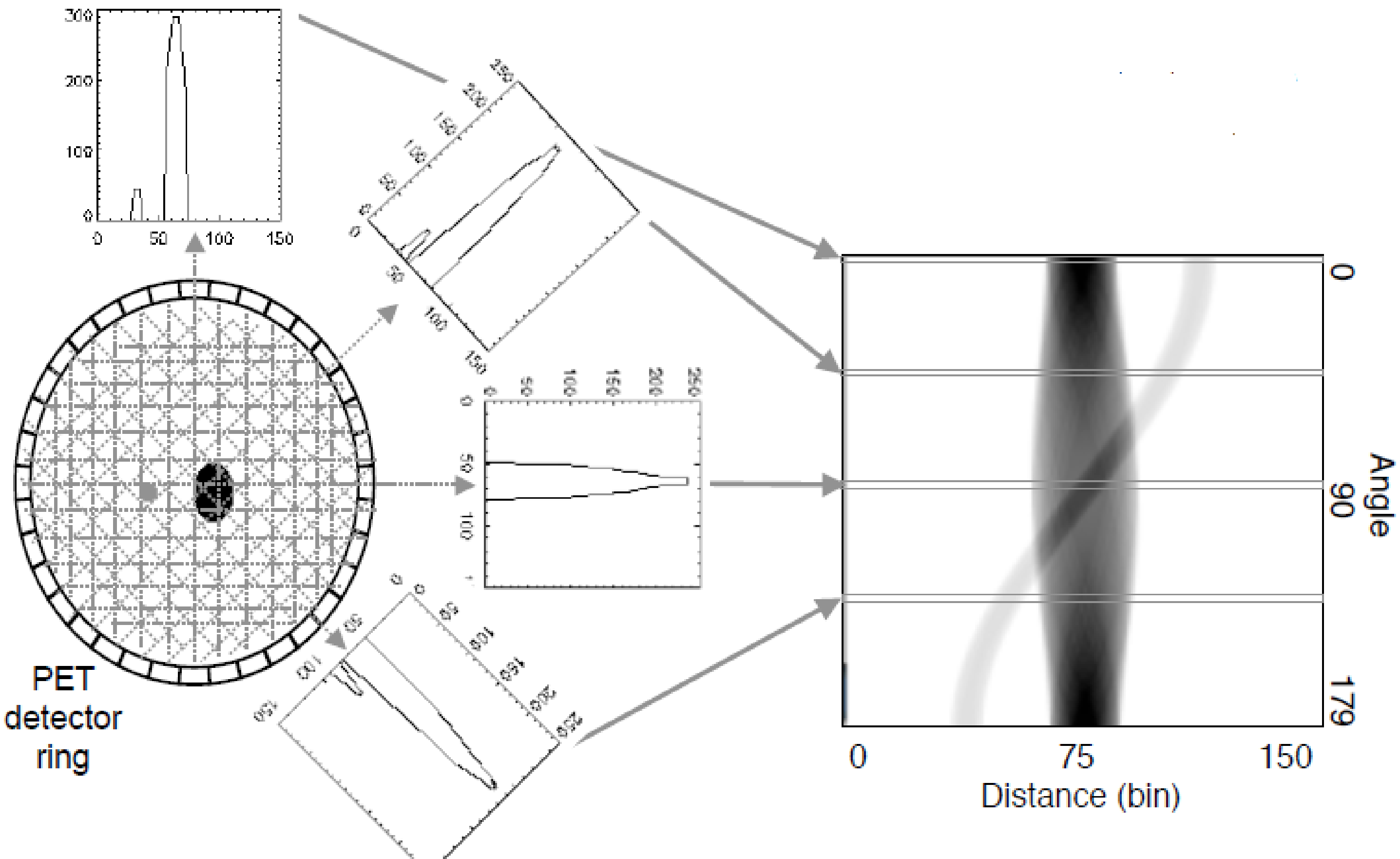
N.B: After scanning certain slices , table is moved along Z plane to obtain next set of slices (as CT)

PET reconstruction (sinogram)

1- Summed counts of each LOR is plotted against distance from the center for each direction angle (θ)

2- sinogram formation:

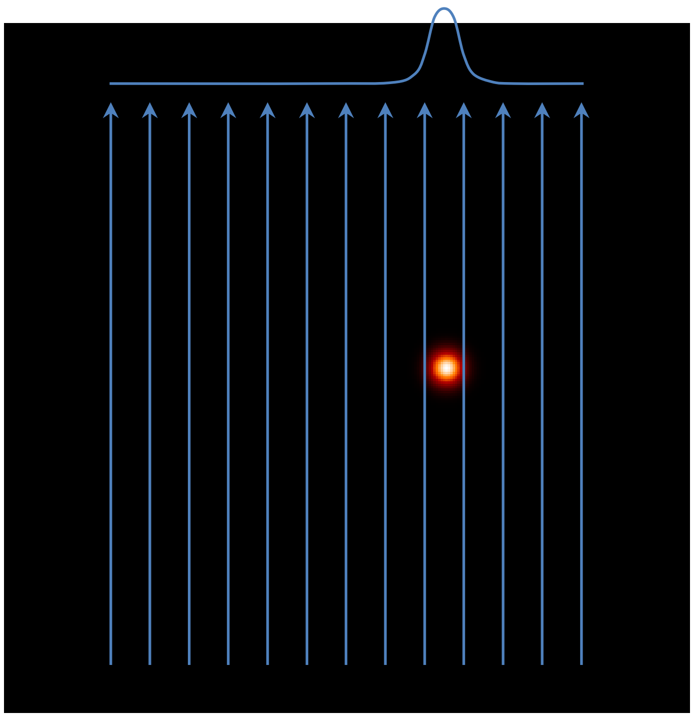
- Two dimensional function of distance from the center against θ (angle)
- Each horizontal row corresponds to all LOR parallel to each other at the same angle of orientation
- A fixed point in an object will trace a sinusoidal path
- Each point of this sinewave is caused by a detector pair
- Each transverse slice through the patient has its own sinogram (composed of all the data for that slice across all of the projection angles
- Each sinogram is analyzed to give the final image



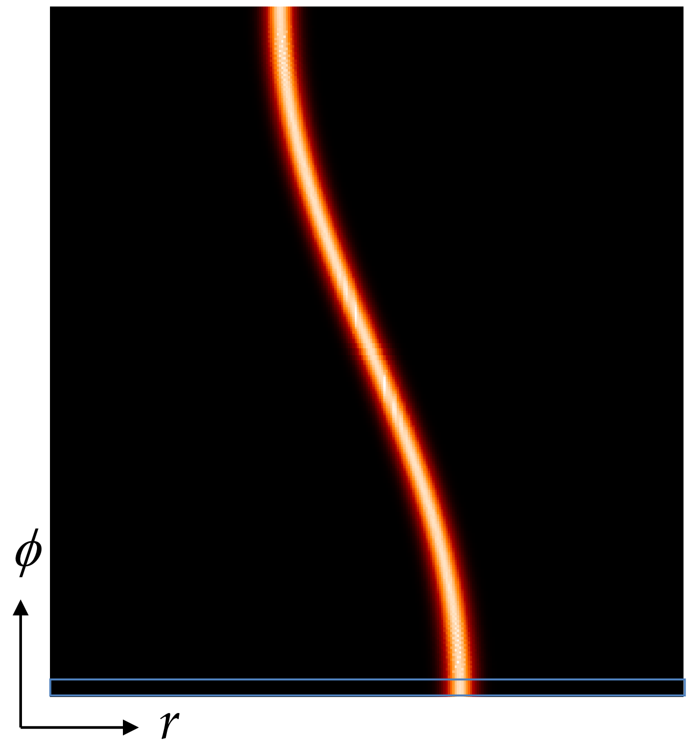
Compare with SPECT

PET image reconstruction

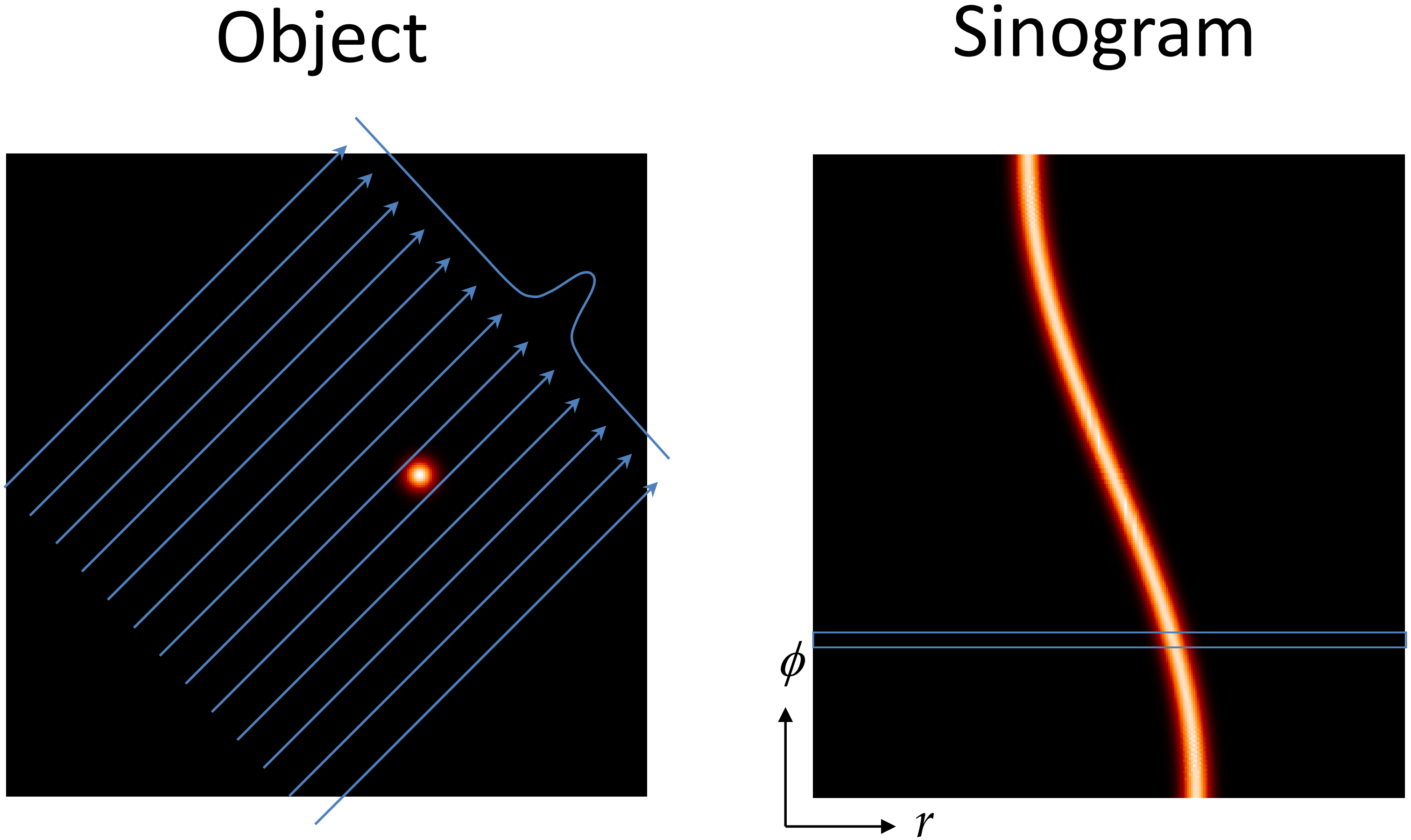
Object



Sinogram

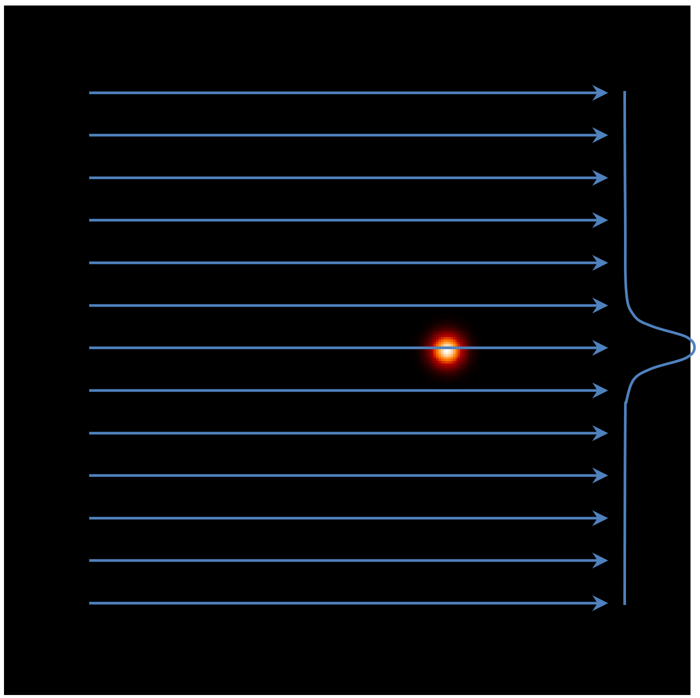


PET image reconstruction

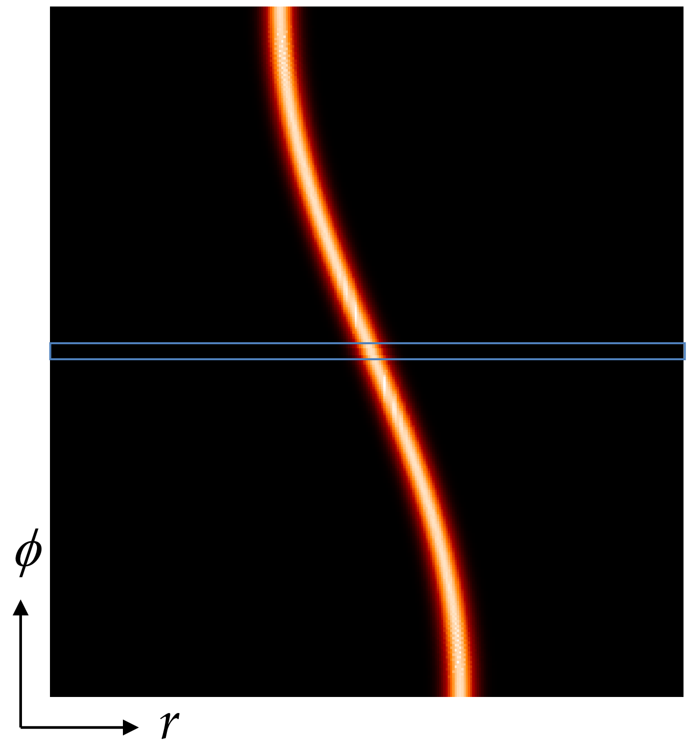


PET image reconstruction

Object

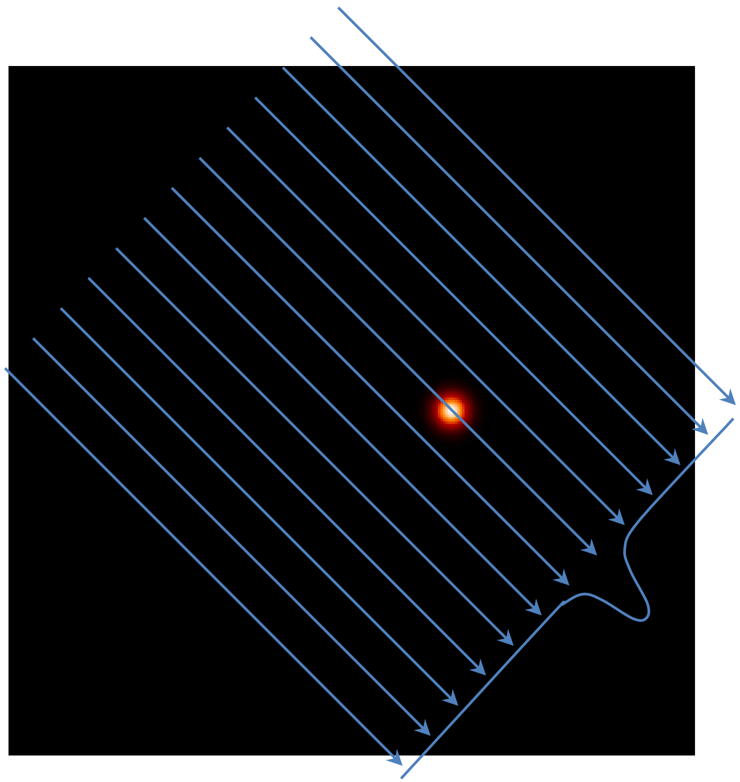


Sinogram

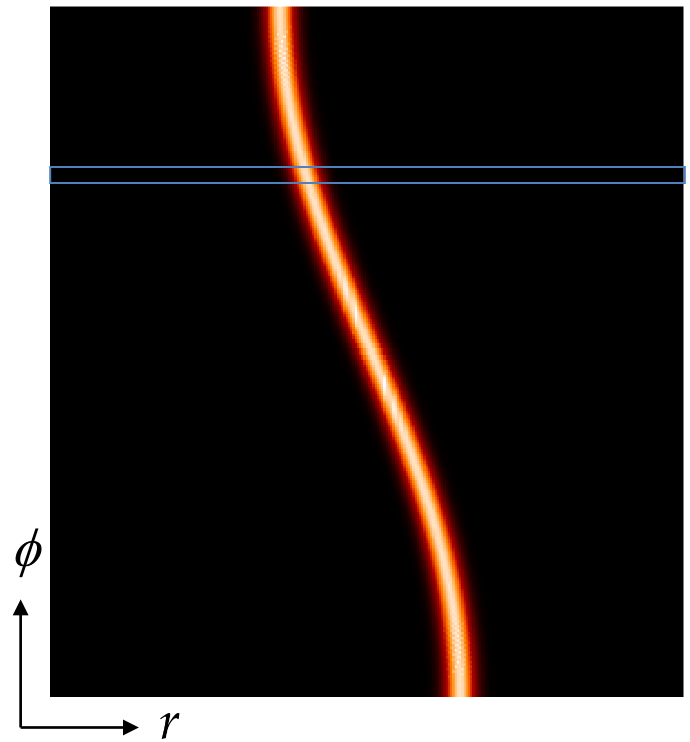


PET image reconstruction

Object

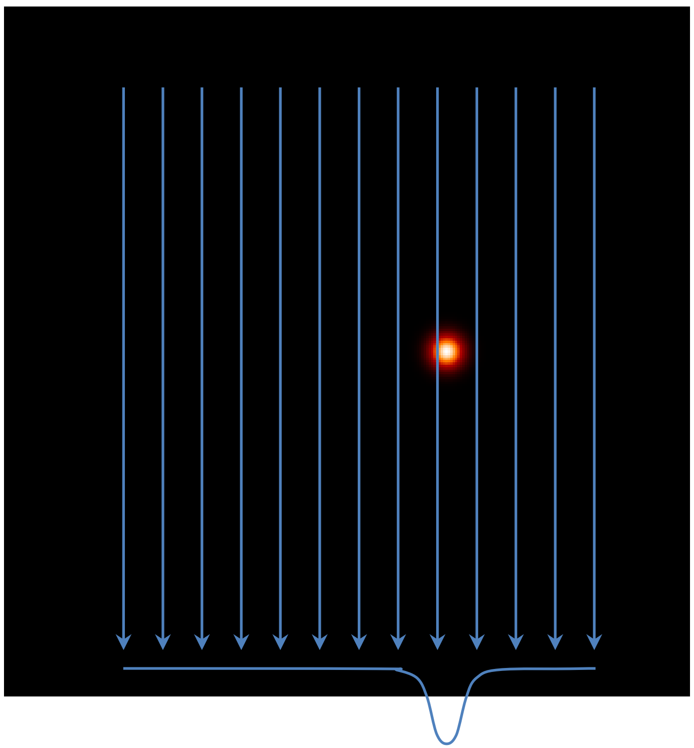


Sinogram

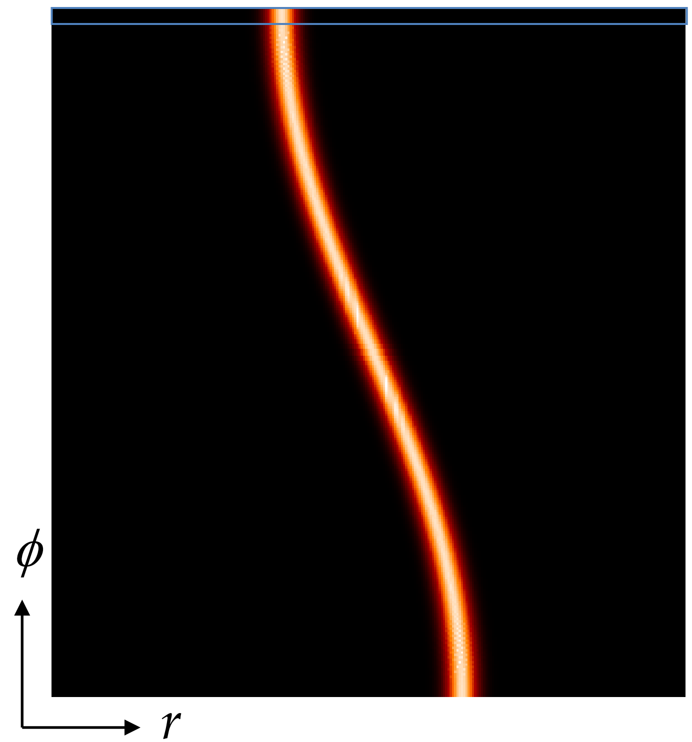


PET image reconstruction

Object



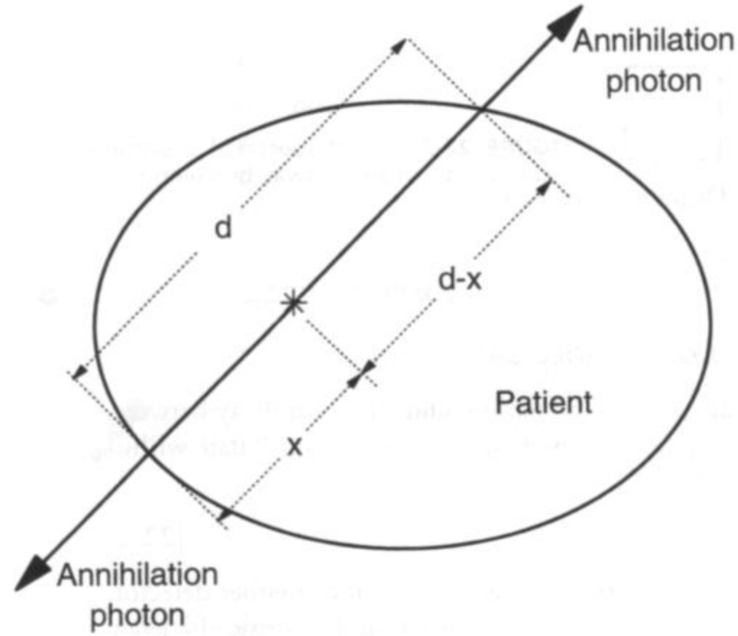
Sinogram

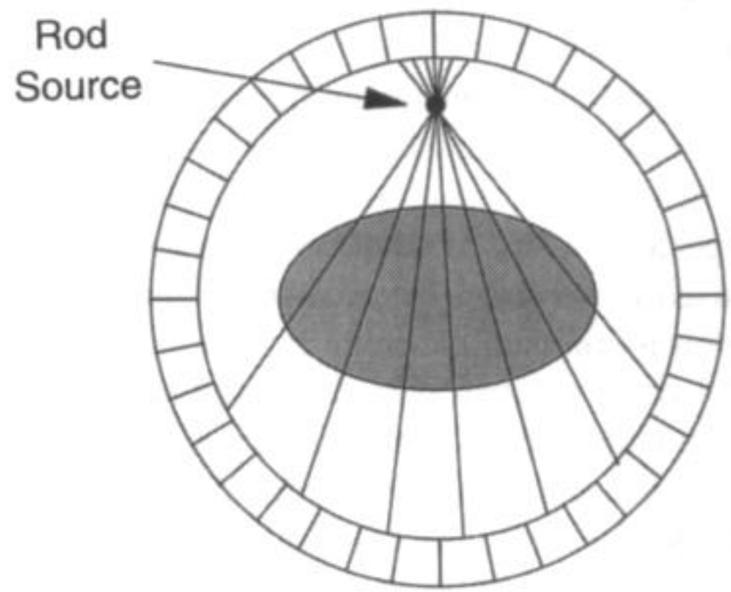


PET algorithms

1- correction of tissue attenuation:

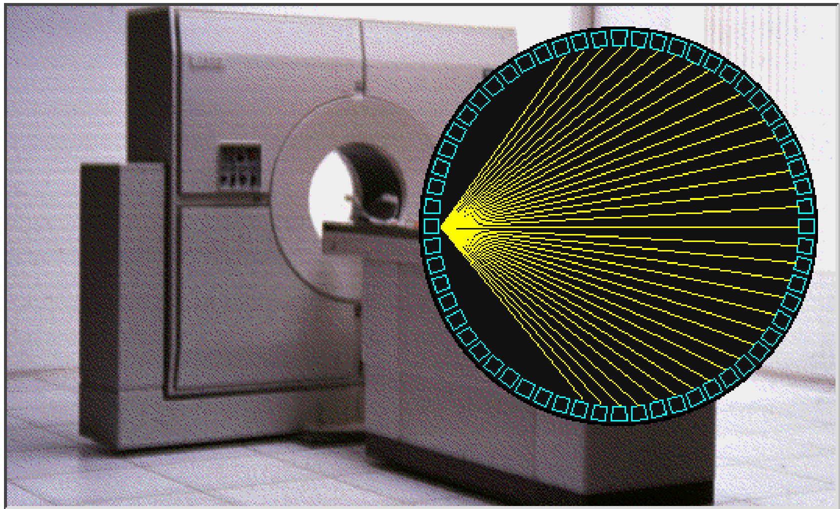
- Attenuation causes a loss of information and, because the loss is not the same for all LORs, artifacts are produced in the reconstructed transverse images
- Loss of information also →noise
- Some PET systems provide one or more retractable positron-emitting sources to measure the transmission of annihilation photons through the patient (e.g. Cs-137)
- Sources revolve around the patient so attenuation is measured along all lines of response through the patient
- i.e. transmission scan is done before the emission scan





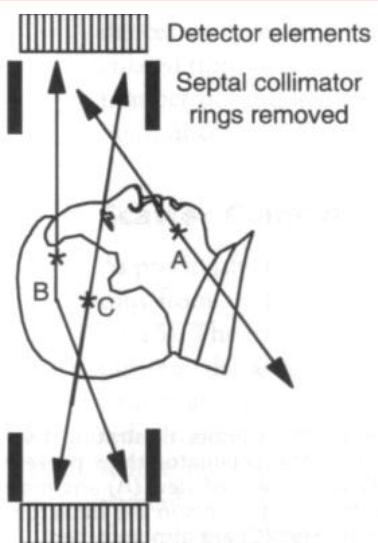
2-arc correction:

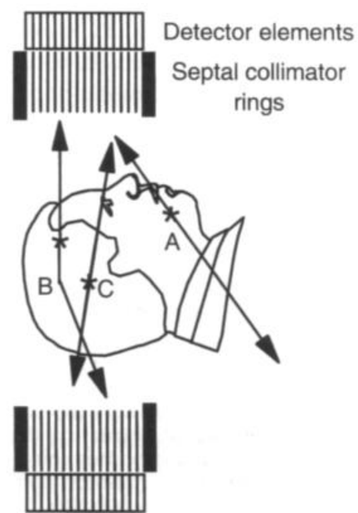
LORs are punched together at the sides of the gantry , and are more uniformly spaced at the center → artifacts specially when scanning large organs (LORs are more likely to be away from the center)

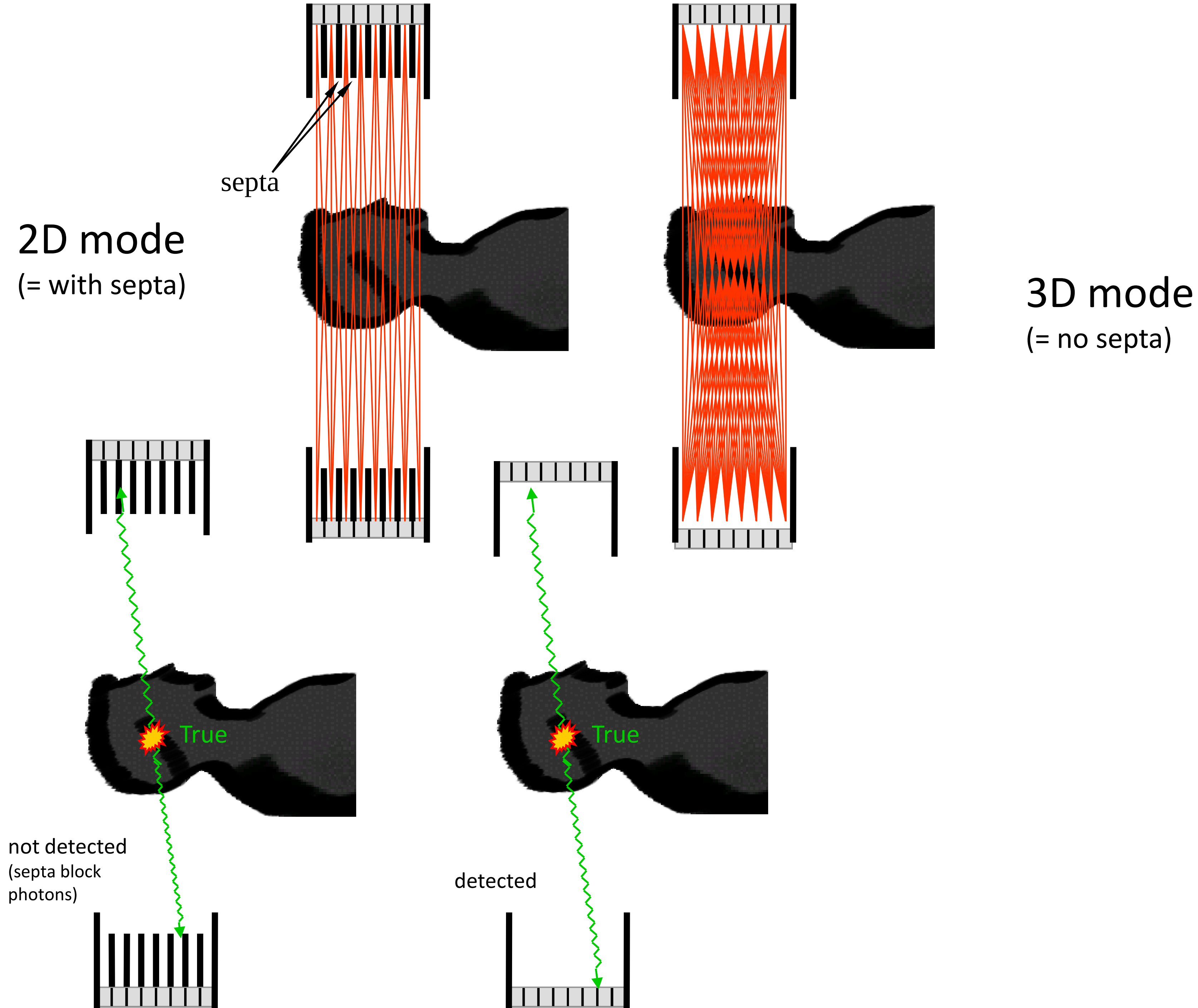


PET data acquisition methods

3D mode	2D mode
Not using septa	Using septa
Collect data from all rings at once	Collect data from one detector ring
Produce 3D singrams = michelogram in each projection angle along Z axis → several (5) axially angled views of the patient are collected	One sinogram per slice
Data must be rebinned before reconstruction into parallel slices	Data is reconstructed into independent parallel slices
High sensitivity (6 times 2D)	less
Scatter fraction = 40%	10%
RANDOMS FRACTION is Worse (no septa)	better
Counting rate is better	worse







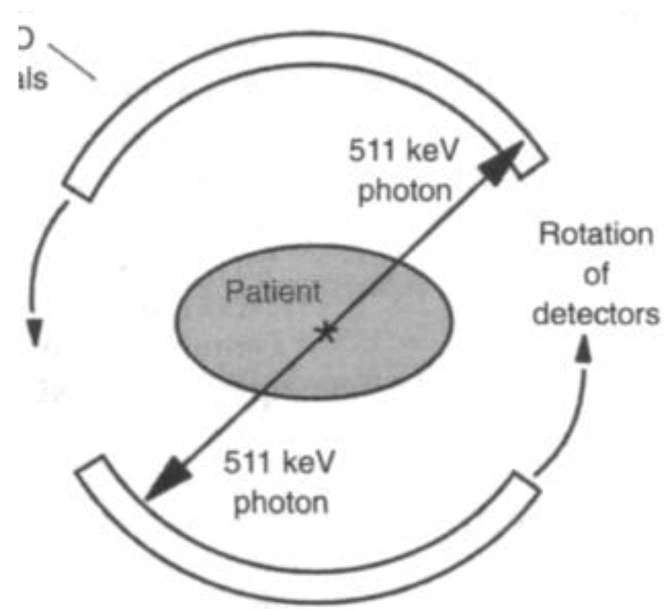
septa
2D mode
(= with septa)
3D mode
(= no septa)
True
True
not detected
(septa block
photons)
detected

Notes:

- Some scanners can retract the septa and operate in either modes
- Both 2D & 3D data acquisition modes can be used to produce 3D images
- PET effective dose to the patient is the same as routine γ imaging (shot t½ of positron emitters compensate for the β energy deposition)

Use of gamma camera as PET scanners

- Dual headed conventional gamma camera can be used as PET scanner
- Conditions:
  - integration of coincidence circuity
  - Rotation of the cameras around the patient without the collimators
  - Thicker crystals of NaI must be used (why?)
- Disadvantages:
  - Higher background noise (↓ contrast) why?
  - Poorer spatial resolution



PET Spatial resolution

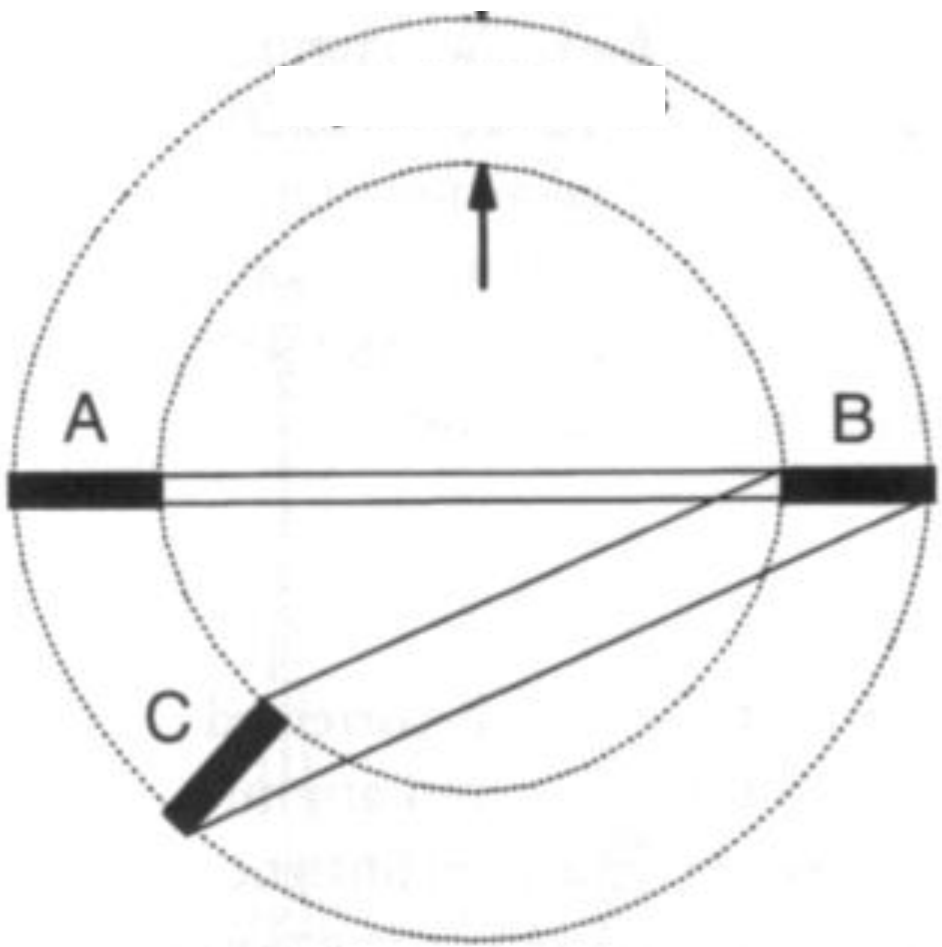
- Whole-body PET systems achieve a spatial resolution slightly better than 5 mm FWHM in the center of the detector ring
- Spatial resolution limited by:

a) intrinsic spatial resolution of detectors

- The most significant factor affecting resolution

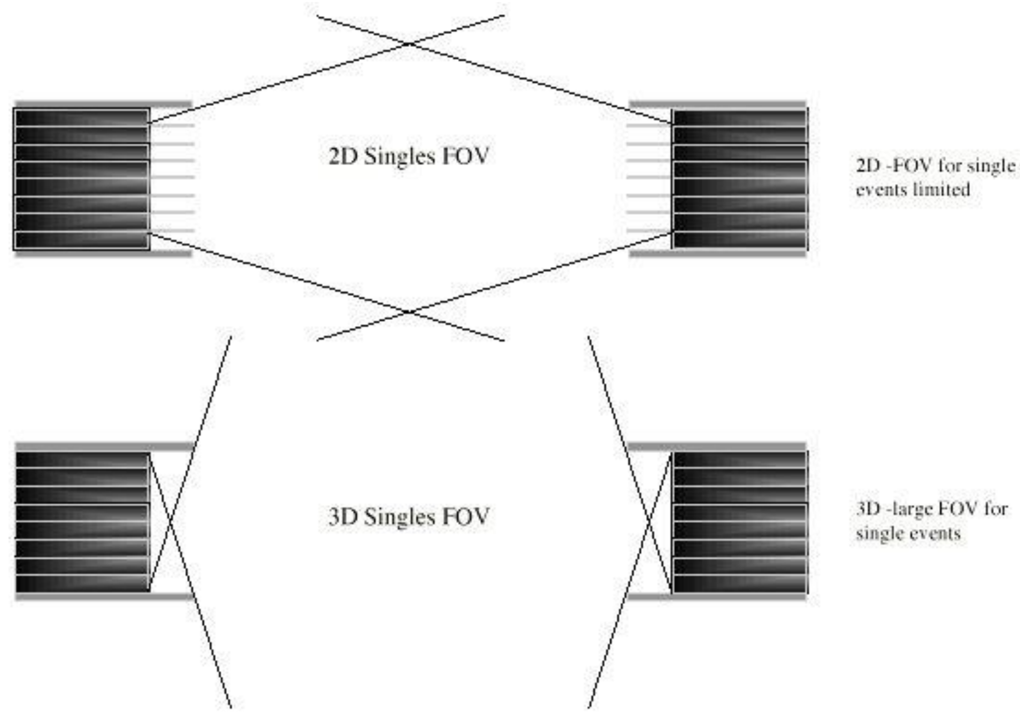
b) Location of annihilation event:

- resolution of PET is best in the center of the detector ring and decreases slightly with distance from the center
- This occurs because of detector thickness and inability to determine the depth where an annihilation occurs
- FWHM is 8 mm at edges of FOV, & 4mm at the center
- *Compare to SPECT where resolution is worse with increase of depth*



c) Width of angle of acceptance of detectors:

The more is the angle of acceptance , the less is the resolution



d)Compton scattering and random events:

both affect FW at tenth maximum more than FWHM

E) distance traveled by positrons before annihilation

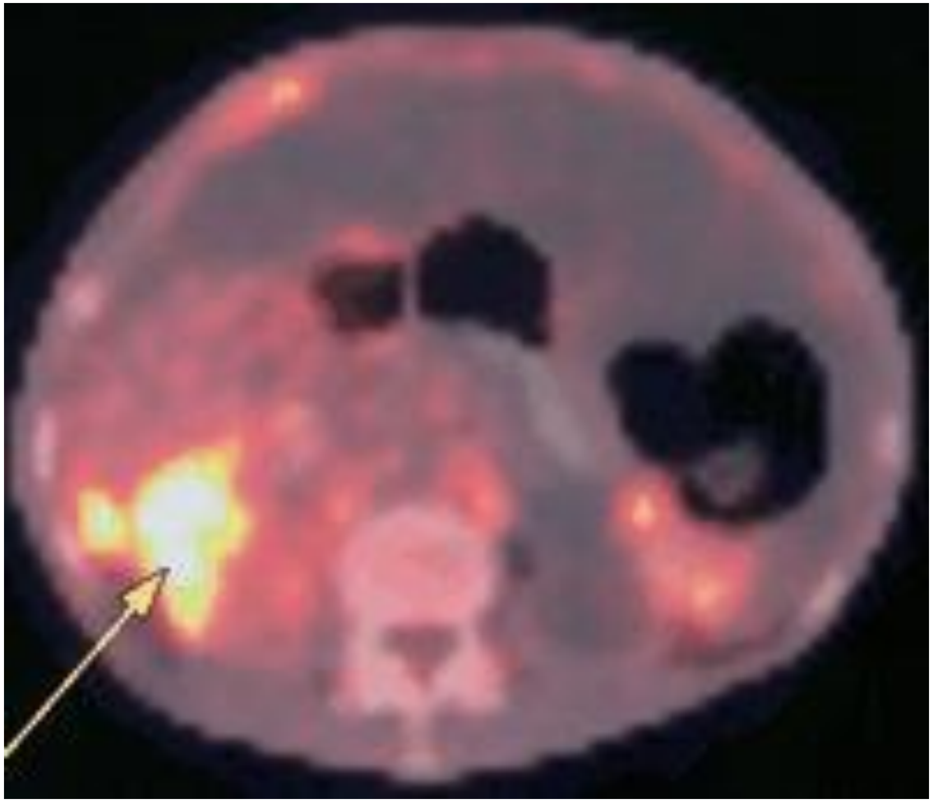
- Distance is determined by maximal positron energy of the radionuclide and density of the tissue
- Radionuclide that emits lower energy positrons yields superior resolution
- Activity in denser tissue yields higher resolution than activity in less dense tissue

F) the fact that annihilation photons are not emitted in exactly opposite directions from each other (if the positron is moving during annihilation)

PET CT scanning

Idea:

PET image for functional information fused with CT (or MRI) for anatomical information (particularly useful in oncology)



Difficulties:

- Adjustment of matrix size
- Matching the transverse planes for co-registration

Solutions:

- Fusion software (complicated by different patient's position and movement)
- Integrated PET CT scanners (mounted adjacent to each other)
  - perfect matching is produced (except involuntary movements)
  - Patient table move to acquire the CT scan , then the table return to position to acquire PET data
  - The CT scan can be also used for PET attenuation correction → whole scan in < 30 min.
  - When used in cardiology: cardiac gating may be mandatory

Many
thanks